CAPE EXPEDITION—SCIENTIFIC RESULTS OF THE NEW ZEALAND SUB-ANTARCTIC EXPEDITION, 1941-45

THE GEOLOGY OF CAMPBELL ISLAND

by

R. L. OLIVER, H. J. FINLAY and C. A. FLEMING

ONWARD
NEW ZEALAND

Issued under the authority of the Hon. K. J. Holyoake
Minister of Scientific and Industrial Research

CAPE EXPEDITION SERIES
Bulletin No. 3

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FOREWORD

THIS SERIES OF REPORTS is based in the main on collections of specimens and data made at the Auckland and Campbell Islands in the years 1941–45. Early in 1941, coast-watching stations were established at Port Ross, Carnley Harbour, and Perseverance Harbour, and the personnel of from three to five men at each were relieved only once a year. Standing instructions issued by Navy Office included a recommendation that the men should, in addition to service routine, record general observations on natural phenomena. In making a selection of suitable volunteers, the Aerodromes Branch of the Works Department was able from 1942 to post at each station at least one man with some professional qualifications in geology or biology. The names of most of them are given below in the list of committee members, but the collections were enriched by the work of many others who made no claim to professional status as naturalists.

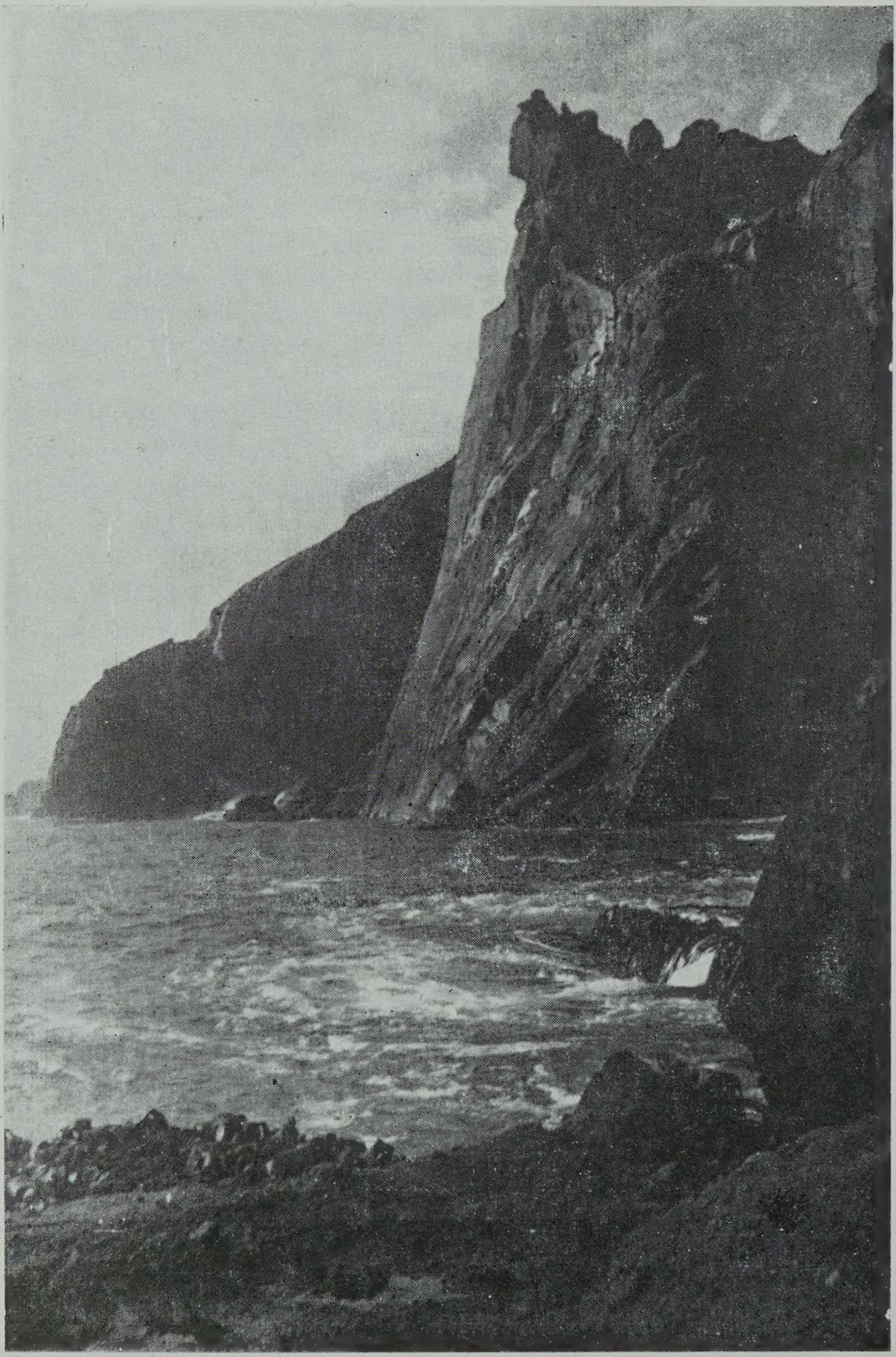
In 1944, coast-watching was abandoned and the Auckland Islands stations closed, but in that year special opportunities were given for visits to the Snares and Disappointment Island. The Campbell Island station was continued for routine meteorological reporting and ionosphere research, but, except for the inclusion of a report on Aurorae as number one of this series, all results of this work are published elsewhere. Biological and geological material collected after 1945 has not generally been included, and these reports may be regarded as covering the work of the "Cape Expedition" which was the war-time code name for parties in the field between 1941 and 1945.

Arrangements for the writing of reports and for publication have been dealt with by a committee consisting of Dr. H. H. Allan (Chairman), Dr. J. Marwick, the Directors of Auckland, Dominion, Canterbury, and Otago Museums, and the following field collectors: C. A. Fleming, J. H. Sorensen, W. H. Dawbin, E. G. Turbott, and R. W. Balham. The Committee is indebted to authors who have undertaken to prepare reports, and to Mr. F. R. Callaghan, Secretary of the Department of Scientific and Industrial Research, and to his staff, for arrangements for publication.

R. A. FALLA,

Hon. Secretary, Cape Expedition Reports Committee.

PLATE 1



Frontispiece.

Campbell Island. View looking north along west coast from below St. Col Peak.

Photo. R. W. Balham.

THE GEOLOGY OF CAMPBELL ISLAND

PART I

PRELIMINARY REPORT ON THE GEOLOGY OF CAMPBELL ISLAND

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The manuscript for all this Bulletin was received on the 4th June, 1948.

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PART I

PRELIMINARY REPORT ON THE GEOLOGY OF CAMPBELL ISLAND

By R. L. Oliver

ABSTRACT

Campbell Island is a small island situated some 400 miles to the south of New Zealand (Fig. 19). It is a much-dissected volcanic cone which was mildly glaciated during the Pleistocene.

The rocks comprise a " schist " basement, perhaps of Mesozoic age, overlain by younger sediments and lavas. The oldest sediments are Upper Cretaceous fresh- or brackish-water quartz conglomerates and carbonaceous mudstones (Garden Cove Formation). Argillaceous limestones of Lower Eocene to Middle Oligocene age overlie them conformably. The Lower Pliocene Shoal Point tuffs and breccias are the next youngest sediments, deposited partly on land and partly in the sea. They are the first manifestation of igneous activity which culminated in the outpouring of basaltic and andesitic lavas (East Coast Formation) to form a volcanic cone.

The development of an erosion caldera, strong marine erosion, and submergence were responsible for the present form of Campbell Island.

The geological history is similar to that of New Zealand and, to a lesser extent, of Macquarie Island. The tectonic position of Campbell Island in the south Pacific is discussed; also the evidence of and causes for Pleistocene glaciation in the south-west Pacific.

The manuscript of R. L. Oliver's paper was prepared in Europe in 1946. During the author's continued absence from New Zealand, the work of editing, preparation for publication, proof reading and compiling the index has been undertaken by C. A. Fleming and other members of the New Zealand Geological Survey without further reference to the author.

INTRODUCTION AND ACKNOWLEDGMENTS

Campbell Island, situated in latitude 52° 33′ S. and longitude 169° 8′ E. (see Fig. 19), is 9 miles long and 9 miles wide at its longest and widest respectively, and has an approximate area of 40 sq. miles. The vegetation consists chiefly of tussock, but scrub grows below 600 ft., particularly in the gullies. Sheep farming was carried on until 1927 when many of the sheep were left and now run wild. Indigenous animal life (seals and sea birds) is abundant. The weather is rigorous, characterized by strong winds and an absence of sunlight.

During 1944, the writer was stationed on Campbell Island as a coast-watcher, with sufficient spare time to enable a fairly complete geological survey to be made. The geological mapping was based on the 40 chains to the inch 100 ft. contour map made by L. C. Clifden, Aerodrome Services, Works Department, in 1942. Dips were measured with an Abney level, and prismatic compass and aneroid barometer were used at times. Samples containing both macro- and microfossils were collected and later examined by Mr. C. A. Fleming and Dr. H. J. Finlay respectively, both of the New Zealand Geological Survey. Their reports are appended to this paper. A comprehensive collection of igneous rocks was also made. Makeshift sectioning apparatus on the island facilitated the preparation of one or two imperfect slides, but most of the rocks have not been sectioned; the writer thus stresses the incomplete nature of this report.

Acknowledgments: The writer wishes to thank the New Zealand Geological Survey for all assistance received, the Dominion Laboratory, Wellington, New Zealand, for chemical analyses, Dr. J. A. Richardson, England, for reading the draft report, and the Bataafsche Petroleum Company, Holland, for doing most of the draughting.

PREVIOUS WORK

Filhol (1885) described a schist basement, overlain by carbonaceous mudstone. He considered that glauconitic sediment was next deposited, and was followed by argillitic limestone and then by cinder breccia and lavas. He mentioned the presence of a granite dyke exposed at North-West Bay. Reischek (1889) noted that Campbell Island was partly sedimentary and partly volcanic. Chapman (1890) described the fossiliferous limestone at North-West Bay and the underlying rock containing iron pyrites. Hector (1895) described the evidence for vulcanism bursting through the Cretaceous sedimentary rocks. Speight (1905) described specimens of diorite (?) and glassy trachyte collected by shepherds on the island. Marshall (1909) considered gabbro to be the basement rock, overlain by quartz conglomerate, argillitic limestone, marine tuffs and lavas. He mentioned that the centre of igneous activity was probably situated to the west of the island.

PHYSIOGRAPHY

General Topography

Physiographically, Campbell Island is a much-dissected volcanic cone. Marine erosion has practically removed the western half of the cone; more of the eastern half remains, however, and the drowned valleys of the larger centrifugal streams form good harbours (Plate 2, Fig. 1).

On the east, the valleys are broad and long, separating planezes of the original cone. On the west, the valleys separate sharp-pointed peaks, many of which are cliffed to the summit (Plate 2, Figs. 2 and 3).

The streams are not large, and are not deeply entrenched. Talus has dammed the stream flowing into Monument Harbour, to form a lake (Plate 4, Fig. 1).

Peat covers the surface of the island, and tarns and swampy depressions are common, particularly on the flatter surface of the eastern part of the island.

Coastal Features

Campbell Island is bounded for the greater part by wave-cut cliffs. The east and west coasts exhibit several striking differences.

On the west and south, strong marine erosion has cut through the lavas and tuffs, and the diversity of rocks thus exposed has resulted in great variation in altitude of the coastline. Vertical cliffs (Plate 1), up to 1,600 feet high, are a feature, in places rising above talus slopes (Plate 2, Fig. 2). Off the coast, numerous islets and stacks (Plate 3, Figs. 1, 2, 3) testify to the rapid retreat of the coastline.

The cliffs on the east are generally lower and more uniform in height. Marine erosion is weaker, and except at Smooth Water Bay, only the lavas have been exposed. Stacks and islets are few.

There are small beaches in places, particularly on the west, and wave-cut platforms (Plate 4, Fig. 3) up to 20 ft. above sea-level indicate small-scale uplift.

Glacial Features

The broad, open valleys (Plate 1, Fig. 2) appear to have been shaped by glaciers. The longitudinal profile of Perseverance Harbour (Fig. 1) is a characteristic glacial profile, though the shallowing at the entrance may be due to deposition of sediment by a longshore current (see Johnson, 1919, Fig. 87).

Fig. 1—North-East Harbour from Mount Lyall.
Photo. L. C. Clifden.

Fig. 2—Mount Paris from further west.
Photo. L. C. Clifden.

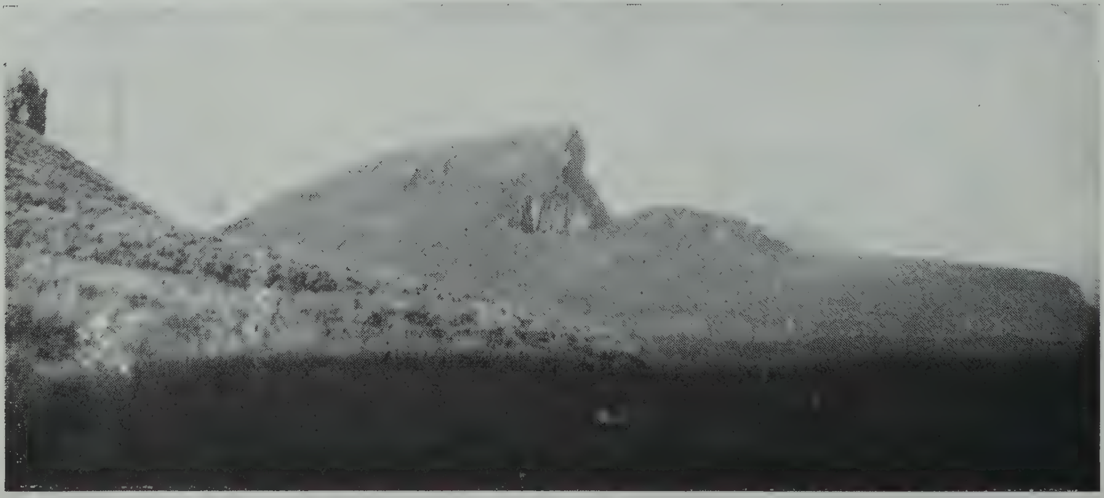

Fig. 3—View showing the extent of marine erosion on Eboulé Peak.
Photo. R. L. Oliver.

PLATE 2

Fig. 1—Looking west along the south coast from between Mount Dumas and Eboulé Peak.

Photo. L. C. Clifden.

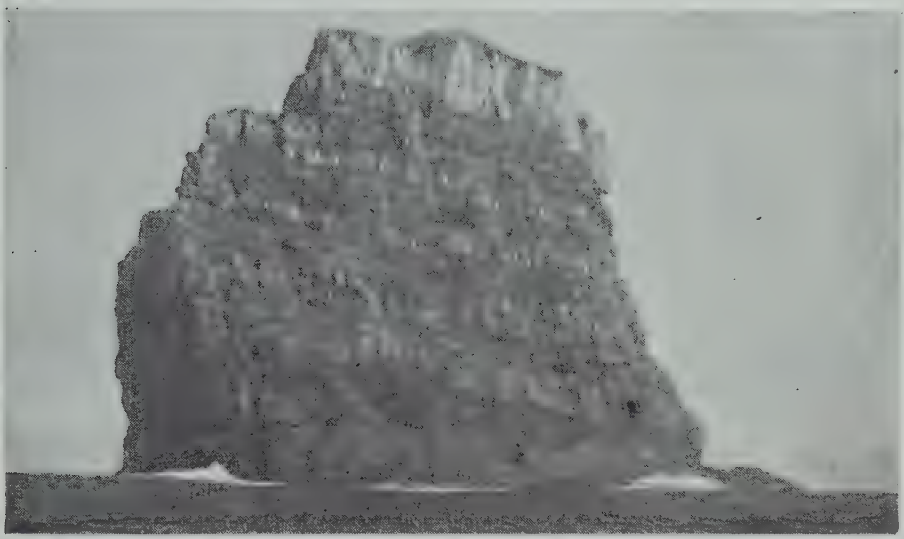

Fig. 2—Steeply cliffed islet south-west of Campbell Island.

Photo. R. A. Falla.

Fig. 3—Erosion remnants on the west side of Monument Harbour.

Photo. R. L. Oliver.

PLATE 3

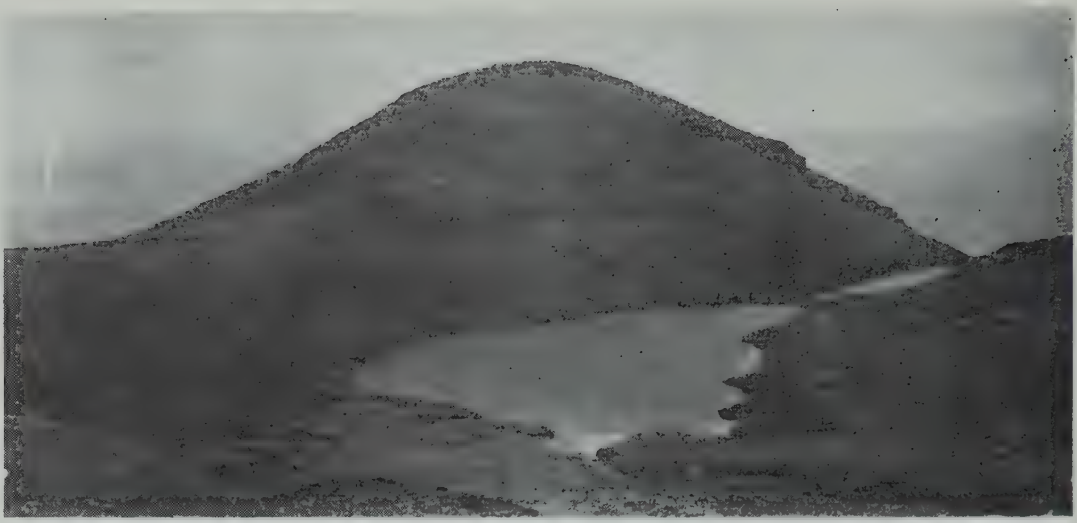

Fig. 1—Mount Puiseux and lake at head of Monument Harbour.

Photo. L. C. Clifden.

Fig. 2—Cliff west of North-West Bay, opposite Dent Island, showing contact between quartz sandstone and schist.

Photo. R. L. Oliver.

Fig. 3—Wave-cut platform, Smooth Water Bay.

Photo. R. L. Oliver.

PLATE 4

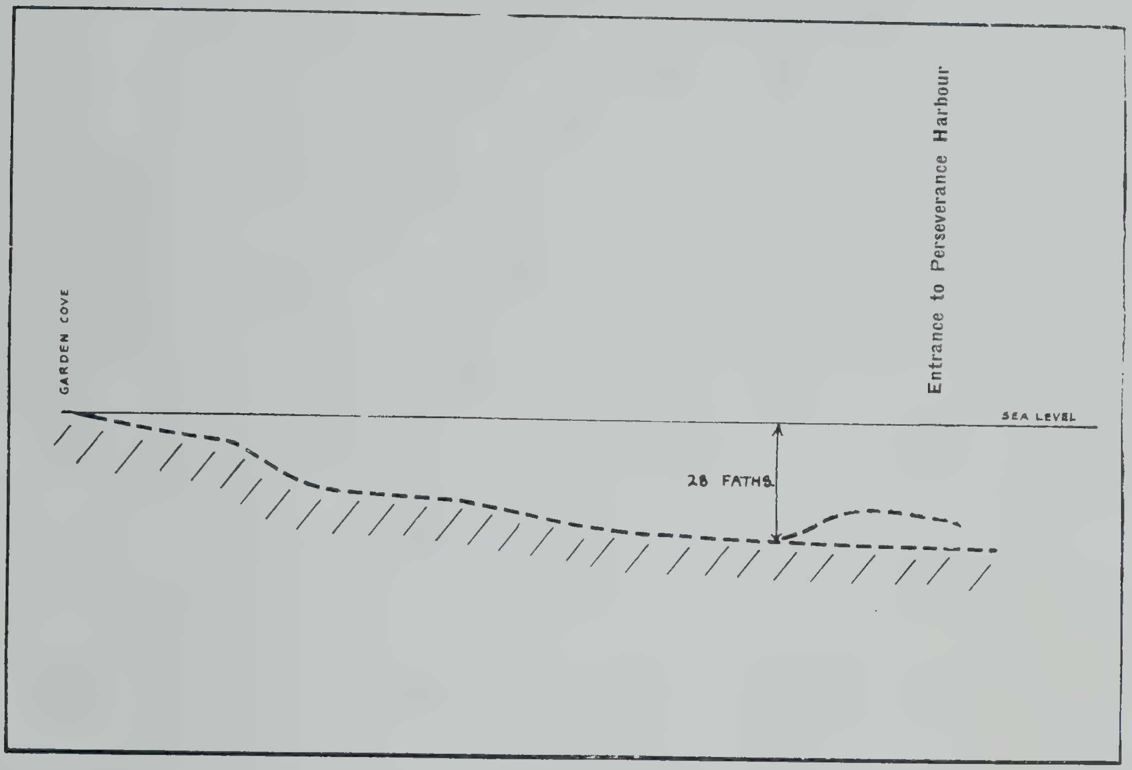

FIG. 1—Longitudinal section of Perseverance Harbour.

Cirques, however, and amphitheatre-shaped valley heads, afford the best physiographical evidence for the glaciation of Campbell Island, though it is probable that structure (the presence of tuffs overlain by more resistant lava) has been partly responsible for their development (see Hinds, 1925, and Cotton, 1944). Cirques occur on the north and south sides of Mount Honey, on the southern slopes of the Lyall ridge, and on the north-east side of Mount Azimuth, between Mounts Fizeau and Faye, and at the head of the valley leading into Camp Cove. The floors of nearly all the cirques are about 500 ft. above sea-level, though one on the south slope of the Lyall ridge is only 200 ft.

The cirques and glaciated valleys of Campbell Island must have been supplied by very small snow fields. According to Griffith Taylor (1914), however, large snow fields are an unnecessary accompaniment of glacial erosion, which takes place more by sapping as the result of freeze and thaw than by the plucking and scouring action of a large ice mass. The western wall of many of the Campbell Island cirques is steeper than the eastern wall. This may be due to the greater sapping of the western wall as the result of a heavier accumulating of snow on a western lee side (sheltered from the prevailing westerlies).

METAMORPHIC ROCKS

Complex Point Formation

Thickness and Distribution

The thickness of the Complex Point Formation cannot be determined, because the base is not exposed.

The coloured geological map shows the distribution of the formation. The cliff exposure west of North-West Bay is continuous for about three-quarters of a mile, but the outcrops at the head of Perseverance Harbour are only a few feet in extent, and only accessible at low tide.

Lithology

The rock of which the Complex Point Formation consists may be a phyllite, but without the evidence supplied by thin sections, no definite identification can be made. For convenience in this report, the rock is referred to as "schist."

When fresh, the rock is hard, compact, and fine-grained; the degree of schistosity differs from place to place, but is nowhere very strong. Individual crystals are unrecognizable. The schistosity of the weathered outcrops at the head of Perseverance Harbour, however, is more obvious, and mica is visible. Quartz veins and lenses are numerous, elongated parallel to, and cutting across, the schistosity; the quartz is more abundant in some places than others, but its abundance bears no relationship to the degree of schistosity.

Age

There is no evidence to indicate the age of the schist. It possibly corresponds to the New Zealand Mesozoic "greywackes," or perhaps to the somewhat older schists of Otago, New Zealand.

SEDIMENTARY ROCKS

Garden Cove Formation

Thickness and Distribution

The distribution of the Garden Cove Formation is shown in the geological map. The thickness exposed in the sea cliffs west of North-West Bay, between the overlying Tucker Cove and underlying Complex Formations, is about 50 ft.

Lithology

Quartz sandstone and conglomerate, and carbonaceous mudstone, constitute the Garden Cove Formation. The lower beds of the formation are composed mainly of quartz pebbles, and the upper layers chiefly of carbonaceous mudstone; but in the intermediate beds, concentrations of quartz sand, quartz pebbles, and carbonaceous mudstone are interbedded irregularly. A few schist fragments are also present. Quartz sand grains, about 1/25th inch in diameter, and cobbles 4 inches across, both occur, but well-rounded pebbles ½ inch in diameter are most numerous.

The best exposure of quartz sandstone is at Complex Point. There, fairly small quartz pebbles are scattered more or less uniformly through a rock of finer texture, lenses of which are almost argillitic. In places, bands of quartz pebbles alternate with bands of quartz sand. No pebbles other than of quartz were seen; the lenses of finer material contain nodules of an iron sulphide. The rock is well-consolidated, and in parts is almost a quartzite. On the east side of Garden Cove, fragments of schist up to 9 inches across are contained in the conglomerate. There are fewer schist than quartz fragments, presumably because of the relatively greater resistance of the quartz to erosion.

The dark grey carbonaceous mudstone predominant in the upper levels of the formation is locally laminated and shaly, but typically uniform in appearance and unbedded. It breaks into irregularly rubbly pieces. On the west coast below St. Col Peak, an exposure shows two feet of intercalated thin layers of fine dark mudstone and fine quartz sand, overlying coarser quartz sand and pebbles ¼ inch in diameter. Unidentifiable carbonized plant fragments up to ¼ inch in length and 1/16th inch in width are contained in the bedding planes. Thin films of powdery sulphur cover the fracture surfaces of the mudstone; the sulphur is doubtless an oxidation product of the embedded iron sulphide nodules.

Another facies of the Garden Cove Formation is exposed immediately east of North-West Bay beach, where the rock underlying the Tucker Cove limestone is an extremely hard argillite, light grey in colour and non-calcareous. There is a gradual change eastward through a hard, sandy, carbonaceous mudstone into the more typical mudstone described above.

Relation to Underlying Beds

The Garden Cove Formation lies unconformably on the Complex Point schist (see Figs. 13 and 14). The contact is exposed on the coast west of North-West Bay (Plate 4, Fig. 2; Plate 5, Figs. 1 and 2); on the west side of Garden Cove, at the head of Perseverance Harbour, schist is exposed, surrounded by quartz sandstone, but the true relationship is obscured by faulting.

Origin of Garden Cove Formation

In New Zealand, the widspread quartz conglomerates or quartz "drifts" at the base of the Upper Cretaceous and Tertiary sedimentary sequence are considered to be fluviatile or lacustrine deposits of similar age, although overlain in different places by marine beds of various ages (see Morgan, 1921, and Macpherson, 1937).

On Campbell Island, the presence of carbonaceous material and plant fragments in the mudstone associated with the quartz pebbles and sand shows that the mudstone was deposited near a source of vegetable matter. The local lamination and fine texture of the mudstone indicate that it accumulated in quiet waters.

A non-marine origin for the basal part of the Garden Cove Formation is thus probable, as for the New Zealand basal "drifts," and its deposition in fresh or brackish estuarine waters is suggested.

Age

Foraminifera from the uppermost beds of the Garden Cove Formation indicate a late Cretaceous age (= New Zealand Te Urian stage*) for the formation. For further details, see Dr. Finlay's paper in this volume (pp. 45–47).

* New Divisions of the New Zealand Upper Cretaceous and Tertiary, by H. J. Finlay and J. Marwick (*N.Z. Journ. Sci., Tech.*, vol. 28, no. 4, pp. 228–236). This paper appeared after the manuscript of Mr. Oliver's paper was received in New Zealand, and new stage names have been incorporated after discussion with Dr. Finlay.—C. A. F.

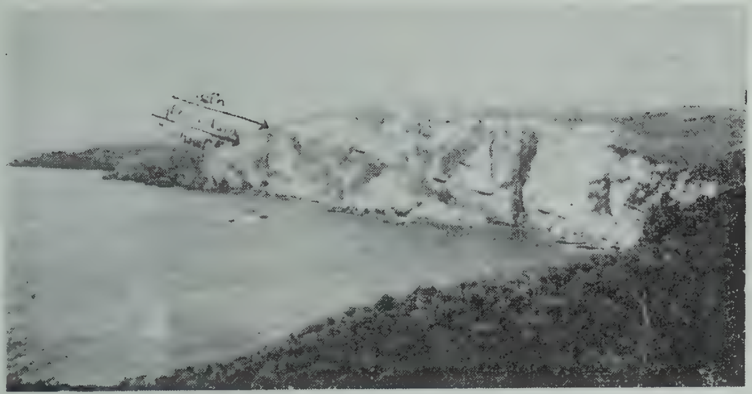

Fig. 1—Cliff west of North-West Bay, showing sequence of limestone over quartz sandstone on schist.
Photo. R. L. Oliver.

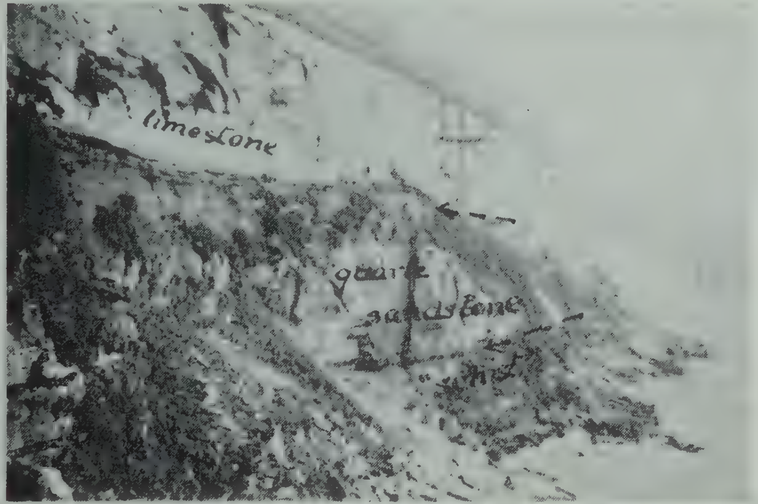

Fig. 2—Cliff west of North-West Bay, showing sequence of limestone over quartz sandstone on schist.
Photo. R. L. Oliver.

PLATE 5

Fig. 3—Exposure of lignite at the top of the cliff just west of Eboulé Peak, showing carbonized plant remains.
Photo. L. C. Clifden.

Tucker Cove Formation

Thickness and Distribution

The distribution of the Tucker Cove Formation is shown in the geological map. The formation is exposed to its greatest height above sea-level on the west and south coasts of the island, due to greater uplift in these localities (see p. 27).

The thickness of the formation in the coastal cliffs west of North-West Bay (Plate 4, Fig. 2; Plate 5, Figs. 1 and 2) is about 500 ft. At, and north of, Windlass Bay, the Tucker Cove limestone appears to be only 300 to 350 ft. thick, but the irregular and disturbed contact with the overlying Shoal Point breccias makes true determination difficult. On the south side of Perseverance Harbour, the formation is 380 ft. thick.

Lithology

The Tucker Cove Formation consists of a white, fine-grained, foraminiferal limestone, which has been formed on a sea bottom comparatively free from terrigenous sediments. Its flaky or shaly nature facilitates rapid disintegration, and large talus slopes have accumulated at the bottom of cliffs. Many foraminifera in the limestone are visible to the naked eye. In addition to foraminifera, molluscs and brachiopods are scattered fairly evenly and abundantly throughout. Isolated rounded quartz pebbles $\frac{1}{4}$ inch in diameter occur, but are not common.

Flint concretionary nodules averaging 4 inches in diameter are common in the Tucker Cove limestone. Their chemical composition is not known, and the word " flint " is used in a general sense. In some of the concretions, flint has replaced limestone only in the centre, and calcium carbonate is mixed with silica in the outer concentric layers. Silicified fossils are included in some concretions. In addition, what appear to be the casts of burrows of marine organisms are embedded in the limestone; most are irregularly branching cylindrical structures which separate cleanly from the surrounding rock.

The limestone varies in hardness: north of Windless Bay, it is soft and can be scratched with the finger nail; west of Windlass Bay it is a dirty grey finely crystalline marble. The reason for the variable hardness is not known; it does not appear to be related to the injection of the gabbro nor of basalt dykes.

Rain water has fluted the finely crystalline rock west of Windlass Bay, and on the south coast, solution has formed two small caves.

Peculiar impressions occur on the surface of some of the limestone blocks. These structures appear to be patterns developed on fracture surfaces, though Dr. J. Marwick (Palaeontologist, New Zealand Geological Survey) has pointed out that the structures are of three dimensions, and considers that they are formed by some organism (personal communication).

Relation to Underlying Beds

The Tucker Cove Limestone overlies the Garden Cove Formation conformably (see Figs. 13 and 14). The contact is exposed for considerable distances between Windlass Bay and North-West Bay beach, in the sea cliff west of North-West Bay (Plate 5, Figs. 1 and 2), and also in Camp Cove at the head of Perseverance Harbour. The beds just below the contact in most cases consist of carbonaceous mudstone.

At Windlass Bay, the limestone immediately above the contact is impure and is mixed with very small angular crystals of a green mineral, and a few sand grains of ill-rounded quartz; three or four inches above the actual contact, the limestone contains none of these impurities. In Camp Cove, the beds at the contact are similar.

A fairly rapid change in sedimentation is indicated, possibly from fresh water lacustrine to shallow water marine conditions.

Age

Foraminifera contained in the limestone indicate an age for the beds extending from the lower Eocene (equivalent to the New Zealand Mangaorapan or Heretaungan stages) to the middle of the Oligocene (equivalent to the New Zealand Whaingaroan); for further details see Dr. Finlay's paper. The molluscs and brachiopods also present in the limestone are of less use as age indicators and have not been studied.

Shoal Point Formation

Thickness and Distribution

The distribution of the Shoal Point Formation is shown on the geological map. The best exposures are in the sea cliffs, but there are several outcrops inland.

In the south-coast cliffs, the thickness of the formation is 450 ft. on the side of Mount Paris and 640 ft. on the south-east side of Mount Dumas, but in both these localities the Shoal Point beds extend below sea-level and the total thickness is not visible. West of Mount Dumas, tuffs are overlain by lavas at 850 ft. above sea-level and underlain by limestone at about 300 ft. The thickness is therefore approximately 550 ft.

Lithology

Within the Shoal Point Formation two facies can be distinguished:

(1) Volcanic tuff, most of which is yellowish-green in colour. Fragments up to 2 inches in diameter.

(2) Volcanic breccia, dark brown in colour. Fragments up to 10 ft. in diameter.

A 465 ft. section in the cliff west of Mount Dumas illustrates the lithology of the tuffs:

(Feet above sea-level)	
665–695	Yellowish-green tuff; fragments up to $\frac{1}{2}$ inch in diameter.
655–665	Blue laminated mudstone.
445–655	Yellowish-green tuff; fragments up to $\frac{1}{2}$ inch in diameter; lenses of laminated mudstone.
445–230	Yellowish-green tuff; fragments $\frac{1}{2}$ inch diameter.

The breccia, contrasting strongly with the tuffs, consists mainly of a fused mass of dark scoriaceous fragments and pieces of limestone, quartz, flint, and "schist" broken from the crater-wall by the exploding lava. The tuffs also contain such fragments.

Where both facies are present in the same vertical section, the tuffs tend to be basal, and the coarser breccia beds form the upper layers; this is very noticeable within an area bounded by the head of Perseverance Harbour, the north-east slopes of Mount Dumas, North-West Bay, and St. Col Peak. Elsewhere, tuffs commonly constitute the whole section between the underlying Tucker Cove limestone and the overlying East Coast lavas.

The presence of fossils in the Shoal Point Formation shows that it was partly deposited in shallow water. The fossils are practically confined to the tuffs. A lens of mollusc, brachiopod, echinoderm, and crinoid fragments is contained in the tuffs exposed on the south-east face of Mount Paris. A similar lens is exposed in the tuffs in the western cliff of Mount Dumas. Relatively fine-grained breccia (fragments 2 to 3 inches diameter), exposed in the sea-cliff midway between Mount Dumas and Eboulé Peak, is fossiliferous, and contains mollusc fossils concentrated thickly in patches. Many mollusc and brachiopod species occur in boulders of coarse tuff on the beach below the western cliff of Mount Dumas, but were not observed *in situ*. Just east of Shoal Point, on the south shore of Perseverance Harbour, coarse and fine tuffs contain a similar rich accumulation of molluscs and brachiopods. A lense of impure limestone in the tuffs in the west coast cliff one mile south of Courrejolles Point contains a few imperfect brachiopods. The fossiliferous layers cannot be correlated because their relative vertical positions are not known.

Some tuffs are current-bedded, a further indication of shallow-water deposition. The cross-bedded units do not dip uniformly in one direction, and so do not indicate the position of a former coastline.

Small deposits of rounded pebbles and lignite lenses indicate a temporary cessation of volcanic activity and resultant small-scale erosion. Lignite lenses within the tuffs are exposed at the top of the cliff just west of Eboulé Peak (Plate 5, Fig. 3), at the tip of the peninsula bounding the west side of Monument Harbour, and in the sea-cliff one mile south of Courrejolles Point, where associated with the latter are rounded lava boulders and gravels. Similar deposits of water-worn lava fragments are exposed in the west-coast cliff one mile north of St. Col Peak, on the south-west face of Mount Paris, and at the top of the cliff midway between Mount Dumas and Eboulé Peak: all these exposures are at the top of the Shoal Point Formation, just below the East Coast lavas, except that on the south-west face of Mount Paris.

Relationship to Underlying Beds

The Shoal Point Formation is unconformable on the underlying Tucker Cove limestone (see Fig. 13, Section IJ, and Fig. 14, Section EF). A period equivalent to the Miocene and half the Oligocene is represented by the unconformity. The limestone was gently folded during this period (Fig. 8), and presumably eroded (because the thickness of the limestone varies—see p. 17), though there are no flint or limestone pebbles at the base of the Shoal Point Formation.

The Shoal Point Formation is seen in contact wtih the underlying Tucker Cove limestone at several places on the west (see, e.g., Plate 7, Fig. 3) and south coasts, but nowhere is the stratigraphic contact uncomplicated by faulting or by " slip fractures."

Origin of Shoal Point Formation

The volcanic vent whence the tuff and breccia fragments were ejected was probably situated at the centre of maximum uplift of the older formations, which were domed up by the pressure of the magma column below (see also p. 37). It appears to have been sited in what is north North-West Bay. A subsidiary cone, the neck of which is perhaps represented by Mount Beeman, was possibly situated at the head of Perseverance Harbour.

The tuffs are widespread on Campbell Island, but the overlying volcanic breccia (composed of relatively large fragments—see Fig. 2) is confined to an area bounded by the head of Perseverance Harbour, the north-west slopes of Mount Dumas, North-West Bay, and St. Col Peak. The centre of activity must have lain near this area (see Ross, Miser, and Stephenson, 1928); the strength of the explosions was insufficient to eject the larger fragments further.

The accumulation of tuffs, combined with the uplift, raised the surface of the sediments above sea-level; most of the volcanic breccia, ejected during the latter stages of the explosive activity, was deposited terrestrially and contains no marine fossils.

Age

The molluscs contained in the tuffs indicate an early Pliocene age for the beds, equivalent to the New Zealand Opoitian or Lower Waitotaran. For further details, see " The Fossil Fauna of the Campbell Island Breccias," by C. A. Fleming, pp. 47–60, in this volume.

Superficial Deposits

Probable Moraine and Fluvio-glacial Deposits

(1) On the floor of the large valley of which North-East Harbour is the drowned lower part, a considerable thickness of detritus consisting of grit and angular frag-

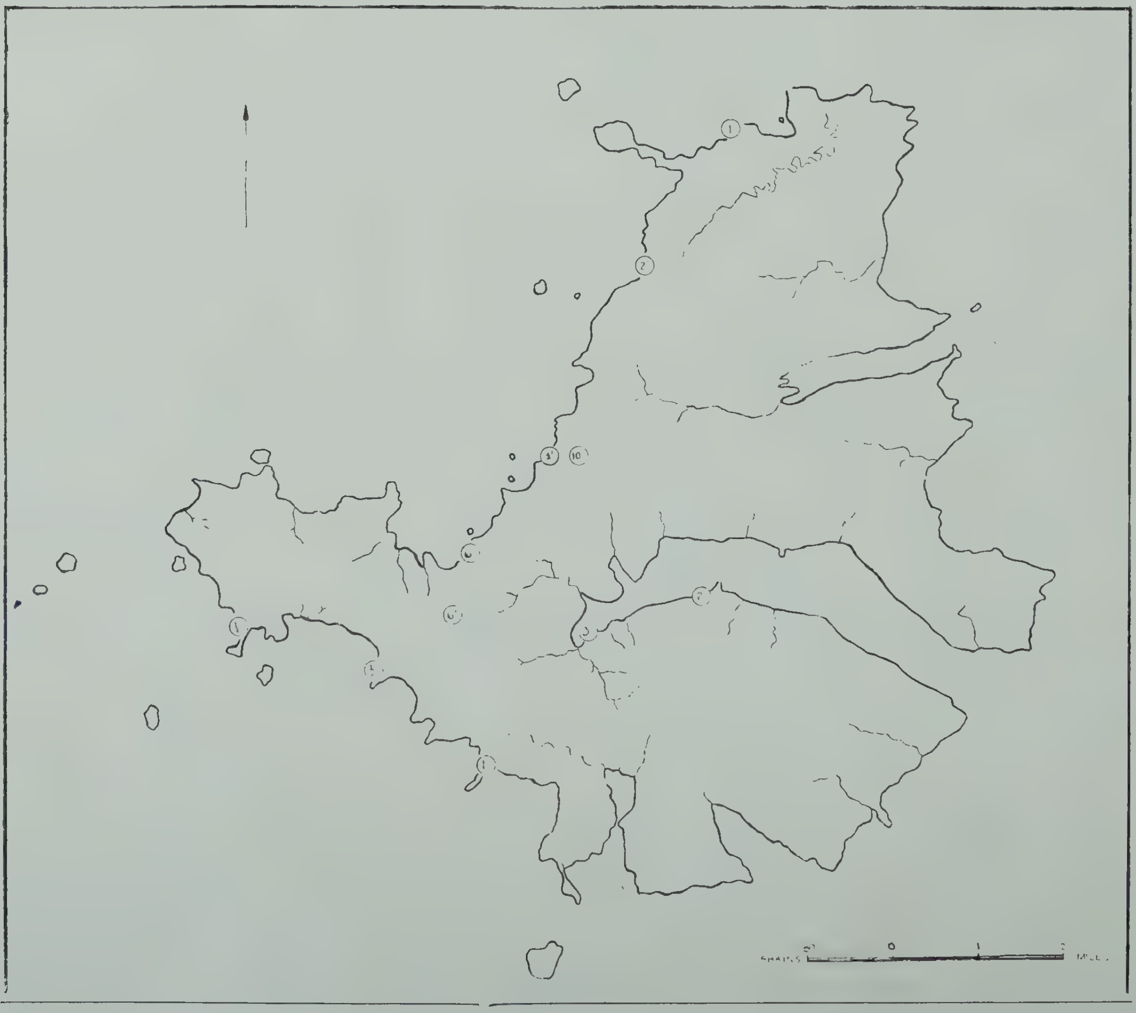

Fig. 2—Map showing the size distribution of Shoal Point Formation fragments. Note that the larger fragments have been deposited close to North-West Bay.

ments up to 4 ft. across forms a projecting ridge into the head of the Harbour (Plate 2, Fig. 1).

(2) On a limestone cliff south-west of Dent Island and the small islet nearby (Plate 6, Fig. 1), there is a cap of detritus consisting of volcanic rocks, one gabbro (?) fragment, a few flint and limestone fragments and including lenses of peat and sand. The weathering and high degree of compaction of this deposit are not common features of moraine (Twenhofel, 1926).

(3) At the head of South-East Harbour, moderately well-compacted agglomerate of ill-rounded fragments is exposed to 40 ft. above sea-level.

(4) The flat tongue-like ridge separating Tucker and Camp Coves (Plate 6, Fig. 2), and the flat tongue projecting from the south side of Mount Beeman, are composed largely of fluvio-glacial material including mudstone and angular fragments up to 4 ft. across.

Raised Beach

(1) In the cliff behind North-West Bay beach, 15 ft. of poorly consolidated sands and gravels overlie gabbro. Angular fragments at the top of the exposure appear to have been washed down from the slopes of Mount Menhir.

(2) At the head of Monument Harbour there is a deposit of loosely-cemented boulders 8 ft. thick. The formation of the lake (Plate 4, Fig. 1) was partly due to the uplift of this deposit.

(3) On the north side of Perseverance Harbour below Mowbray Hill, rounded boulders are exposed up to 8 ft. above the present beach, resting on Shoal Point breccia.

Talus

(1) In Perseverance Harbour, the lower slopes of both the north and south sides are covered with talus. The thick accumulation below the cirque on the north side of Mount Honey may be in part morainic.

(2) At the cliff edge overlooking Penguin Bay, loosely angular rubble mixed with silt and clay has been washed from the hillside above.

Stream Alluvium

At the head of Tucker Cove there are ill-rounded pebble deposits 2 ft. thick, and at the head of Garden Cove alluvium consists of ill-rounded pebbles of quartz, limestone, and volcanic rock.

Wind-blown Pebbles (see also Mawson, 1943)

Wind-blown pebbles were noted at the top of the cliff just east of Windlass Bay, 200 ft. above sea-level. They consisted of well-rounded limestone pebbles. Lava pebbles, two inches in diameter, were found on the west side of Monument Harbour, 150 ft. above sea-level.

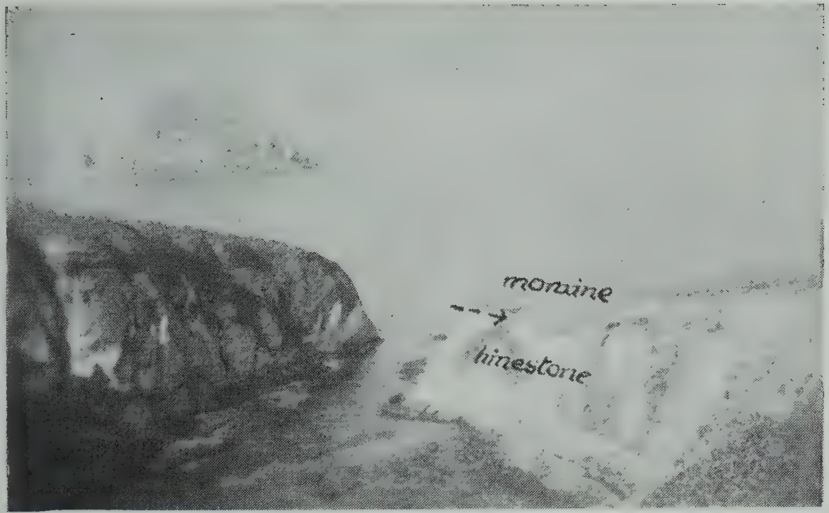

Fig. 1—Looking towards Dent I. from near Yvon Villarceau Peak, showing moraine overlying Tucker Cove limestone.
Photo. R. L. Oliver.

Fig. 2—View of flat spur between Camp and Tucker Coves.
Photo. R. W. Balham.

Fig. 3—Looking south along the bottom of the west-coast cliff towards Windlass Bay, showing dykes dipping towards the presumed source of the lavas in the middle of North-West Bay.
Photo. R. L. Oliver.

Fig. 4—The summit of Mount Lyall.
Photo. L. C. Clifden.

IGNEOUS ROCKS

Gabbro

(See Marshall, 1909)

Distribution

The geological map shows the approximate distribution of gabbro. Owing to the absence of outcrops on the lower western, southern, and eastern slopes of Mount Menhir, the exact boundary of the gabbro is not clear, but it is deduced from the surface contours. A gabbro xenolith was found in a basalt dyke at Middle Bay, indicating that the gabbro extends underground further east than is apparent at the surface.

Lithology

The fresh hand-specimen is grey, with abundant glassy or pinkish felspar and augite crystals. The felspars are white and opaque in the weathered rock, causing it to resemble a granite or a syenite rather than a gabbro.

Thin sections (Marshall, 1909) reveal a coarse, even grain with prominent plagioclase felspar (acid labradorite) and augite. Brown biotite, apatite and ilmenite (or magnetite) occur in smaller amount.

Gabbro, apparently spheroidally weathered to a marked degree, enclosing angular fragments of a fine-grained green rock up to 6 in. in diameter, outcrops in the sea cliff 300 yards south of Complex Point. The writer cannot explain why such a feature should be so restricted in area and so sharply differentiated from the surrounding gabbro. The included green rock was not found elsewhere on the island.

Relationship to Other Rocks

The contact between the gabbro and the bounding rocks is considered to be a fault contact, because it does not appear that the gabbro could have been injected in the molten condition into its present position. It was not injected before the deposition of the Garden Cove Formation, for there are no gabbro pebbles in the conglomerate. Nor could injection have occurred after the deposition of the Tucker Cove limestone because of the absence of calc-silicate hornfels and similar metamorphic derivatives of limestone. In any case, it is considered that there never could have been a sufficient thickness of sediments overlying the gabbro in its present position to allow its crystallization as a plutonic rock.

Both the eastern and the western boundary of the gabbro is exposed in the sea cliffs. The cliff exposure of the roughly vertical western boundary is not accessible at close quarters, but, from a distance, considerable movement appears to have affected the rocks. The eastern boundary is exposed behind the eastern end of North-West Bay beach. There, the rocks are shattered and broken and extremely weathered; there also, movement has occurred.

Age

The gabbro was possibly injected in the molten state to just below the surface in the late Jurassic and owes its present position to up-faulting in the late Pliocene (see page 31).

Flows (East Coast Formation)

The geological map shows the distribution of the East Coast Formation. On the west and south, the formation remains as isolated patches capping the hills; on the east, it is more continuous.

The thickness of the formation exposed in the south-east face of Mount Paris is about 1,100 ft. On Mount Honey, the thickness is also 1,100 ft., and on Mount Azimuth, 1,200 ft.

Lithology

The East Coast Formation consists of a succession of apparently basaltic and andesitic lava flows, average 50 ft. in thickness, most flows being red and scoriaceous near their upper surface. Some of the flows exhibit columnar jointing.

The flows are typically exposed a mile and a half east of Courrejolles Point:

Top	1. Fine dark grey lava; numerous large ($\frac{1}{2}$ in. long) felspar phenocrysts.
	2. Fine grey fissile rock.
	3. Vesicular lava; large felspar phenocrysts.
	4. Very fine grey lava; small ($\frac{1}{8}$ in. long) isolated felspar phenocrysts.
	5. Extremely vesicular lava; numerous large felspar phenocrysts.
	6. Grey lava; large glassy felspar phenocrysts.
Apparently one flow.	7. Medium-grained, grey lava; prominent large felspar phenocrysts. 8. Hard, fine, fissile, grey lava; small isolated phenocrysts.
	9. Red scoriaceous lava; extremely vesicular.
Apparently one flow.	10. Fine dark grey lava; finely vesicular; no phenocrysts. 11. Medium-grained, dark grey lava; numerous large glassy felspar phenocrysts.
	12. Fine, dark grey, hard lava; a few small phenocrysts.
	13. Red scoriaceous lava; large glassy felspar phenocrysts.
Bottom	14. Medium-grained, grey lava; large glassy felspar phenocrysts.

The lavas seem to vary in texture not only from flow to flow, but also within the same flow (see Nos. 7 and 8, 10 and 11 above).

Tuff layers, mainly red, but in places greenish-yellow, separate the flows in places. They are lenticular, and it was possible to suggest correlation between only two of them, namely between a lens exposed on the western cliffed face of Mount Azimuth and a similar layer a mile further north.

Relationship to Underlying Beds

The East Coast Formation is both conformable and disconformable with the underlying Shoal Point Formation.

The presence of lava pebble and boulder deposits in the upper levels of the Shoal Point Formation (page 19) indicates that the East Coast Formation was erupted, at least locally, on to an erosion surface. That the surface of the Shoal Point beds was exposed above sea-level at the time of lava extrusion is also suggested by the absence of pillow lavas at the base of the East Coast Formation. No movement, however, affected the Shoal Point beds before extrusion of the East Coast lavas; the general stratifications of the two formations in the south and south-west coastal cliffs are parallel, though current-bedding of the tuffs tends to obscure the true strike and dip. The relationship between the East Coast and Shoal Point Formations is therefore disconformable. Interbedding of the East Coast lavas and Shoal Point beds however, just east of Eboulé Peak and in the south-east face of Mount Paris, is suggestive of continuous deposition, and of a conformable relationship.

Age

There is no internal indication of the age of the East Coast lavas. Their extrusion immediately after the deposition of the Shoal Point Formation of lower Pliocene age suggests a Pliocene age for the lavas.

Dykes and Other Igneous Rocks

Distribution of Dykes

By far the greatest number of dykes is exposed in the rocks bounding North-West Bay. At the head of Perseverance Harbour, too, numerous dykes cut limestone, breccia, and carbonaceous mudstone. Dykes also outcrop along the south coast between Mount Paris and Eboulé Peak, and in the west-coast cliffs.

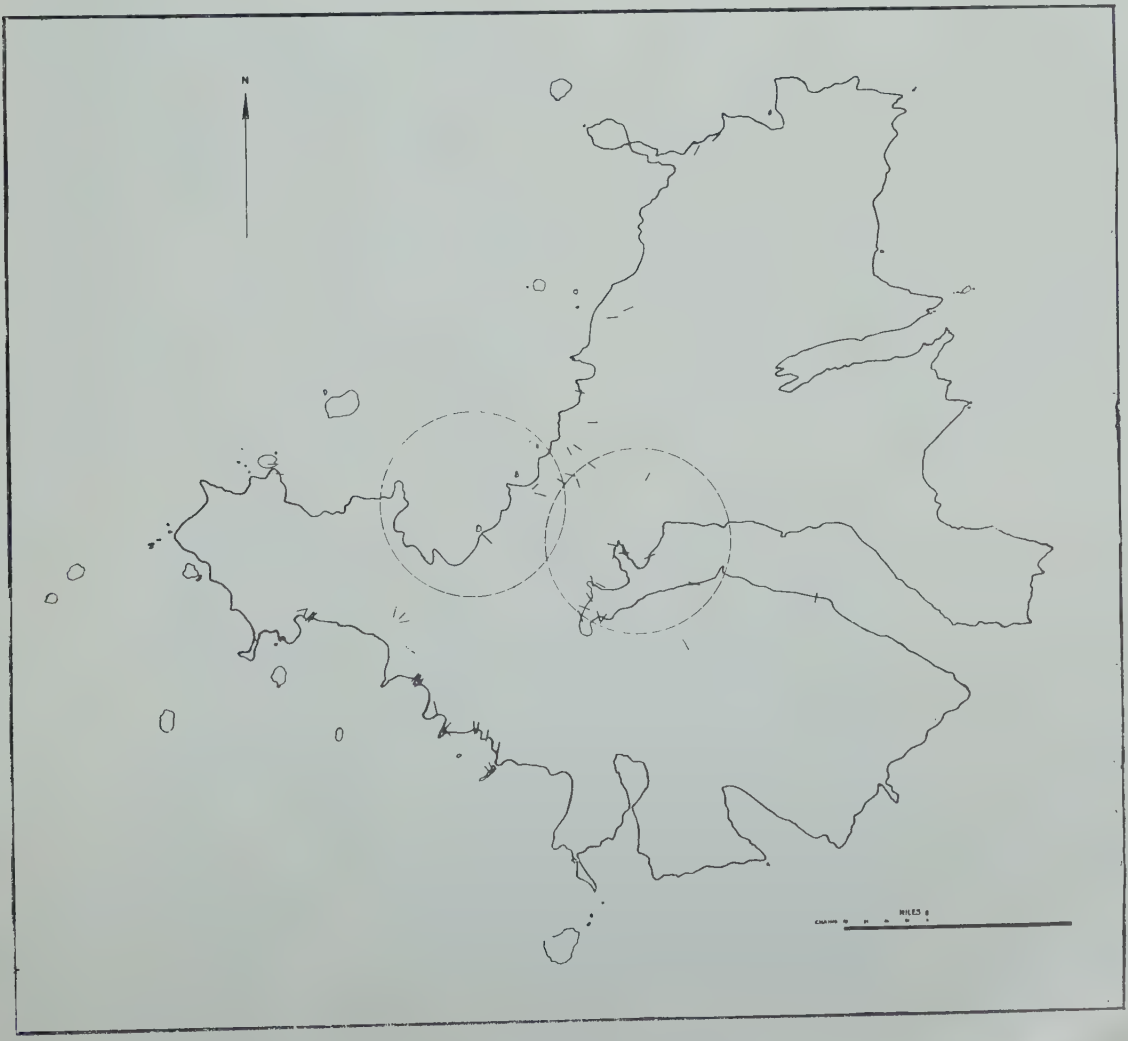

Fig. 3—Map of dyke system.

Orientation of Dykes

Most of the dykes are vertical, and those vertical dykes which have a distinct orientation have been mapped (Fig. 3). Of 55 dykes, 31 radiate from or outcrop within a circular area centred in North-West Bay, and 32 radiate from or outcrop within a circular area centred on Mount Beeman.

A few dykes are not vertical. In the sea-cliffs of eastern North-West Bay, several dykes striking north–south dip steeply seawards (Fig. 4), and two such dykes project from the water at the base of the cliff (Plate 6, Fig. 3). The orientation of these dykes strongly suggests that their source was beneath the waters of North-West Bay.

Many dykes are irregular masses and exhibit no orientation (Plate 6, Fig. 4).

Mount Beeman

A thin section shows the rock of which Mount Beeman is composed to be an olivine basalt containing many large olivine phenocrysts altered to serpentine. Macroscopically, the rock exhibits well-developed columnar jointing (Plate 7, Fig. 1).

A subsidiary volcanic cone was possibly situated at the head of Perseverance Harbour, but there is no evidence to indicate whether Mount Beeman is the neck of a volcano or an igneous intrusion which did not reach the surface.

Age of Dykes

That the dykes were formed after the main body of lavas (East Coast Formation) was extruded is evident from the fact that many dykes cut the lavas.

Origin of Flows and Dykes

The vent (or vents) from which the East Coast lavas and the dykes were emitted is (or are) presumably the same from which the fragments of the Shoal Point

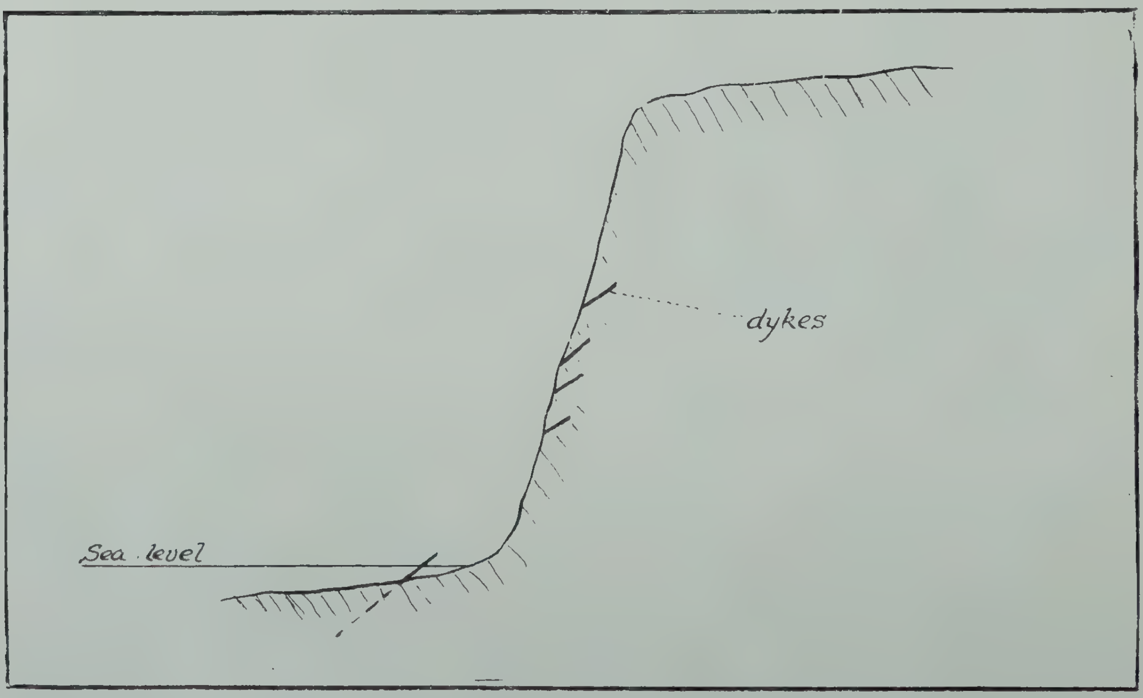

Fig. 4—Cross-section of cliff bounding the east side of North-West Bay, showing orientation of dykes.

Fig. 1—Columnar basalt of Mount Beeman.
Photo. R. L. Oliver.

Fig 3 (right)—View of west-coast cliff just north of Windlass Bay, showing penetration of limestone by lava, and irregular contact of limestone and breccia.
Photo. R. L. Oliver.

Fig. 2—Looking north along the west-coast cliff, showing penetration of limestone and breccia, by lava, just north of Windlass Bay. *Photo. R. L. Oliver.*

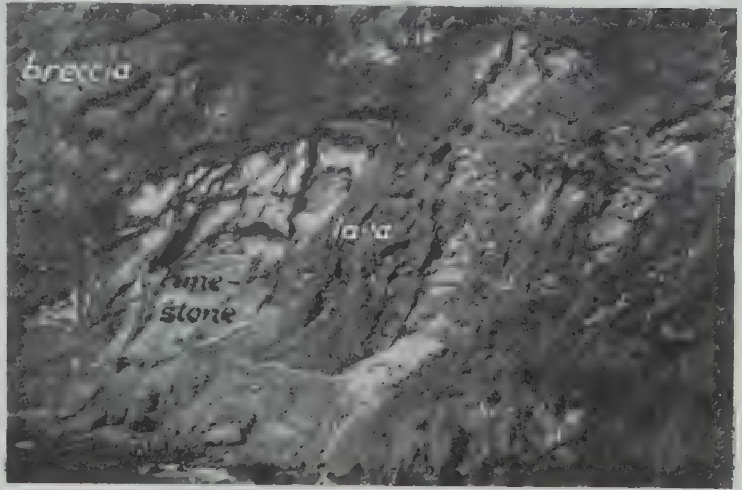

Fig. 4—View of cliff just north of Windlass Bay showing penetration of breccia and limestone by lava.
Photo. R. L. Oliver.

PLATE 7

Formation were ejected. There is evidence that the main vent was situated in the present position of North-West Bay and that Mount Beeman is the neck of a subsidiary cone. The evidence may be summarized:

(1) In the west-coast cliffs a mile north of Windless Bay, the great number and concentration of dykes (Plate 7, Fig. 3) and the complex relationship of Shoal Point breccia, Tucker Cove limestone, and lava (Plate 7, Figs. 2 and 4) indicate that violently disruptive volcanic activity has occurred. In places, fragments of Tucker Cove limestone up to 20 ft. in diameter are embedded in Shoal Point breccia, hundreds of feet away from any breccia-limestone contact. It seems that the higher part of the cliff at this point is most broken and injected by the greatest number of dykes; the limestone along the bottom of the cliff is relatively undisturbed. This would suggest that the centre of activity was some distance from the present cliff. Nowhere else on the island is there evidence for such violent volcanic activity.

(2) The directions of dip of the lava flows appear to radiate from North-West Bay (see geological map). On the other hand, they could be considered also to radiate from the head of Perseverance Harbour.

(3) The majority of vertical dykes radiate from, or outcrop near, North-West Bay and the head of Perseverance Harbour. Also, dykes in the cliffs of North-West Bay slope towards a point in the middle of the bay (see Fig. 4).

(4) The fact that the oldest rocks are at their greatest altitude in the vicinity of North-West Bay suggests that the centre of uplift of the basal sedimentary formations, due to pressure of a magma column, was in this locality. This centre would be the point from which the lavas and tuffs were emitted.

Quartz Veins

The quartz veins appear to have been formed in two periods (see Filhol, 1885). The oldest quartz forms lenses and laminae both parallel to and oblique to the plane of schistosity in the schist. The segregation of this quartz was possibly associated with the development of the schistosity, and is thus older than any of the other rocks on the island; it is this quartz from which the pebbles of the Garden Cove conglomerates were derived.

Most of the quartz veins were formed comparatively recently, and sills and dykes (the last manifestation of lava activity) are penetrated by lenses and veins of quartz in several parts of the island. This quartz represents the last phase of a cycle of volcanic activity which commenced with ash deposition and continued through several phases of lava extrusion (see Filhol, 1885).

STRUCTURE

Folding

Campbell Island is structurally a dome (Fig. 8) formed of the Shoal Point and East Coast Formations; the centre of the dome lies where North-West Bay is now situated. The older Garden Cove and Tucker Cove Formations, which were also involved in the uplift, are exposed to their greatest height above sea-level near the centre of the dome. Severe marine erosion has destroyed the main outline of the dome.

Fig. 1—West-coast cliff between St. Col Peak and Mt. Azimuth, showing fault.
Photo. R. L. Oliver.

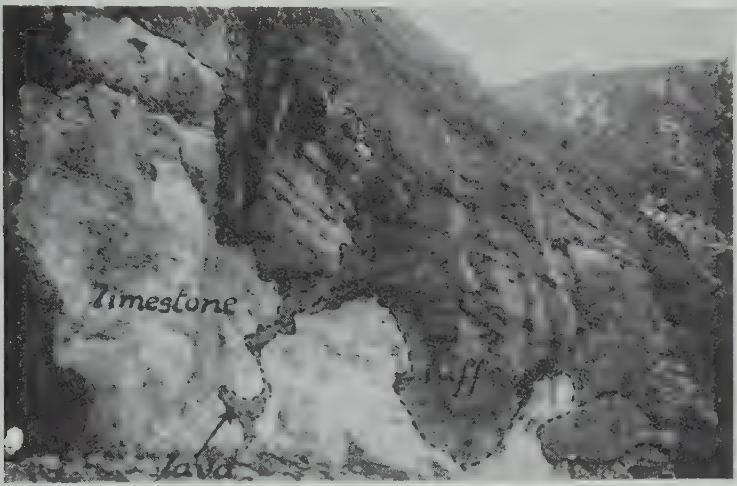

Fig. 2—Cliff just north of Yvon Villarceau Peak, showing penetration of marine tuffs and limestone by contorted dykes.
Photo. R. L. Oliver.

Fig. 3—Cliffed western side of Eboulé Peak. Note on the left of the cliffed face the contorted thin white line indicating the presence of a fault.
Photo. R. L. Oliver.

PLATE 8

The Tucker Cove limestone and Garden Cove Formation, unconformably underlying the Shoal Point beds, are also gently folded as the result of earlier movement. (In the absence of stratification in much of the Garden Cove mudstone, its bedding is considered parallel to the junction with the overlying Tucker Cove limestone.) The map shows these beds dipping gently to the south-east north of Windlass Bay, to the south-south-west at Windlass Bay, and more steeply to the south-west, west of North-West Bay. At the head of Perseverance Harbour there is indication of a pitching anticline or a small dome. The writer has not been able to correlate the coastal exposures; the Tucker Cove and Garden Cove Formations, where elsewhere exposed, have been disturbed by faulting or slumping. Joints and small scale fractures break the limestone in several places.

In the Complex Point schists, which are unconformable below the Garden Cove conglomerate, the schistosity dips at 9° to North 95° East at Complex Point; further west, the schistosity dips at 25° to North 142° East. In the absence of thin sections, no mention of the lineation or comparison with the lineation of the New Zealand schists can be made.

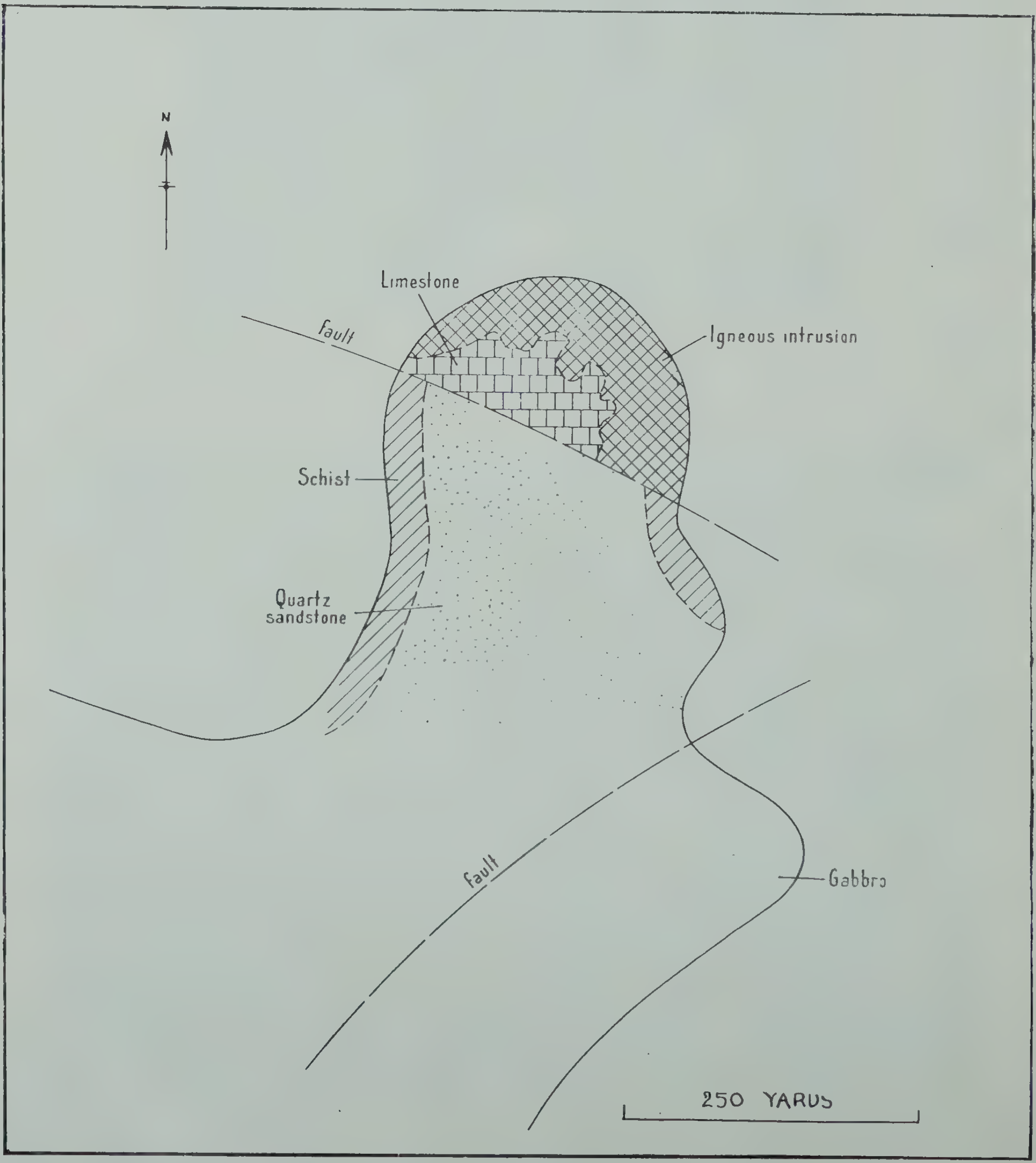

FIG. 5—Diagram showing the relationship of the beds at Complex Point.

Faulting

(For location of faults, see geological map)

The Campbell Island dome is broken by many faults, most of which are younger than the lava flows. The majority are small and do not affect very much the general structure of the island.

The writer is unable to interpret the structure illustrated in Plate 8, Fig. 1. A vertical fracture separates Shoal Point beds in the upper part of the exposure from an unidentified weathered flaky rock which is exposed nowhere else on the island. Shoal Point tuffs are undisturbed below. Movement may have been horizontal, transferring the "unknown rock" from a site now occupied by the sea. A more precise age determination of the faulting than post-breccia cannot be given.

A clearly-defined fault in the cliffs north-west of St. Col Peak (see Fig. 14, Section GH) separates Shoal Point breccia from Tucker Cove limestone and Garden Cove carbonaceous mudstone. As the base of the breccia is not exposed on the down-throw side, the exact throw of the fault cannot be determined; but it at least 450 ft. There is no evidence that the fracture penetrates far inland. Its apparent association with the results of igneous dyke activity in the cliffs further south indicates a post-lava flow age for the fault.

At Complex Point, Tucker Cove limestone on the north-east has been down-faulted a maximum of 50 ft. against schist and Garden Cove quartz sandstone (see Fig. 5). At the fault, isolated patches of quartz pebbles which have been forced into the schist give the erroneous impression that the latter is intrusive into the quartz sandstone.

In the cliffs west of North-West Bay no fault plane is exposed, but a fault is inferred from field evidence (see Fig. 6 and Section CD, Fig. 14). The fault probably does not extend far inland. Its throw is about 100 ft. The beds west of the fault dip more steeply than those to the east; tilting may have accompanied the movement.

A fault has down-thrown the "Paris–Yvon Villarceau" block approximately 200 ft. (see Section CD, Fig. 18). Part of the cliff at the north-western end of this fault is shown in Plate 8, Fig. 2, in which a distorted dyke, and irregular interpenetration of Shoal Point tuffs and Tucker Cove limestone are clearly visible. The fault is younger than the lava flows; in the north face of Yvon Villarceau Peak the East Coast lavas lie alongside Shoal Point tuff. The steep north-eastern slope of the Yvon Villarceau Peak–Mount Paris saddle may be an obsequent fault-line scarp (see Cotton, 1922, page 177 and Fig. 186), perhaps accentuated recently by glaciation.

Faults on the east (see Section AB, Fig. 13) and south sides of Filhol Peak are inferred from the anomalous angle of dip (25°) of the lava flows on Filhol Peak, an angle which does not conform with that on Mount Honey, Mount Dumas, or Puiseux Peak. Fig. 7a illustrates the relationship of the flows on Filhol Peak to those exposed on the south coast, and Fig. 7b shows the relationship between those on Mount Dumas and Mount Honey. The two faults are possibly two sides of a down-faulted "Filhol" block.

In the cliff just west of Eboulé Peak a small up-faulted block has dragged up the beds on either side (see Plate 8, Fig. 3).

The position of the gabbro mass exposed on Mount Menhir and in the cliffs of western North-West Bay is considered due to faulting (see pages 21 and 22).

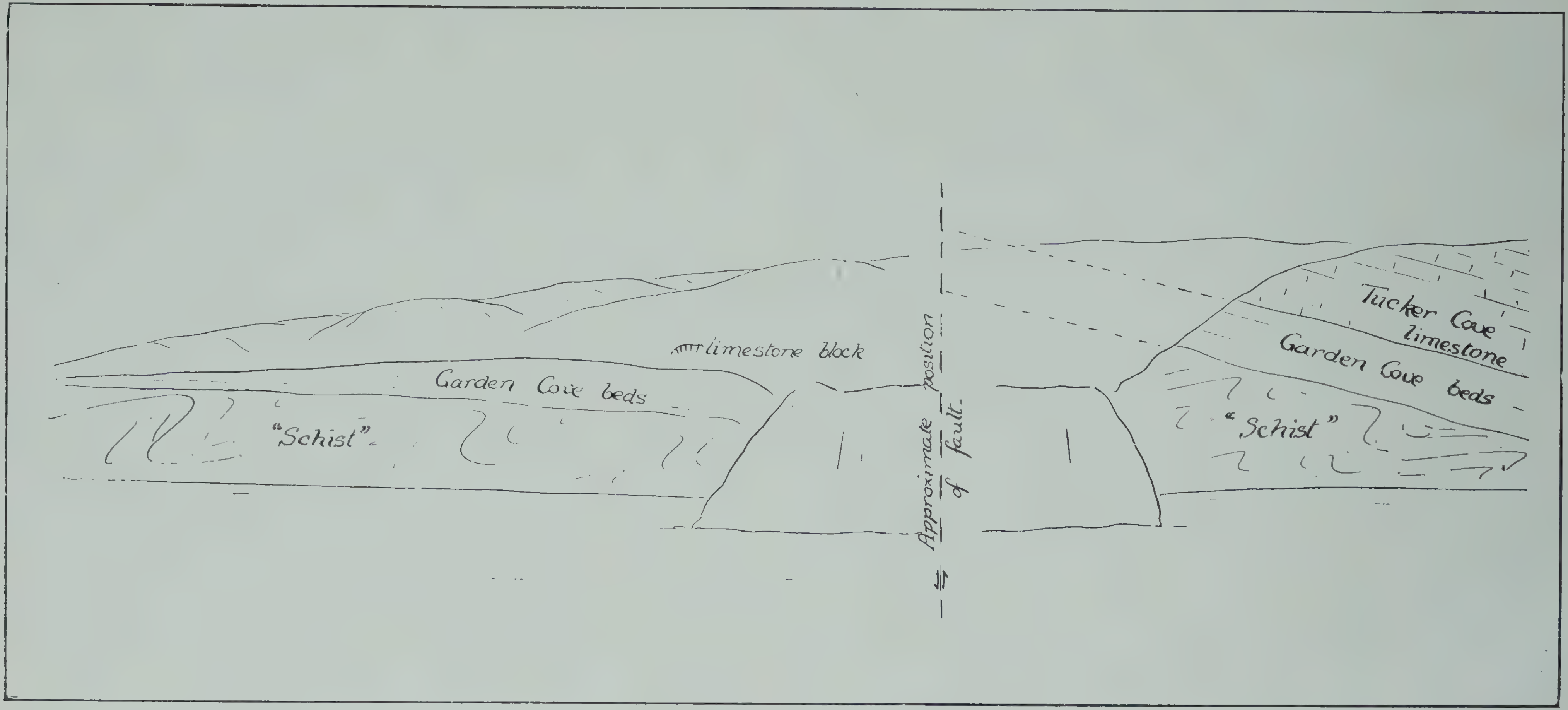

FIG. 6—View of cliffs west of North-West Bay showing relationship of beds and position of probable fault.

The continuation of the fault as a ring round the gabbro mass is admittedly hypothetical, though ring faults have been described in other parts of the world (e.g. Bailey, 1944).

Faults are visible in the sea-cliff half a mile south-west of Mount Azimuth. Deposition of Shoal Point breccia seems to have been followed by lava extrusion and then faulting, prior to the emplacement of more lava.

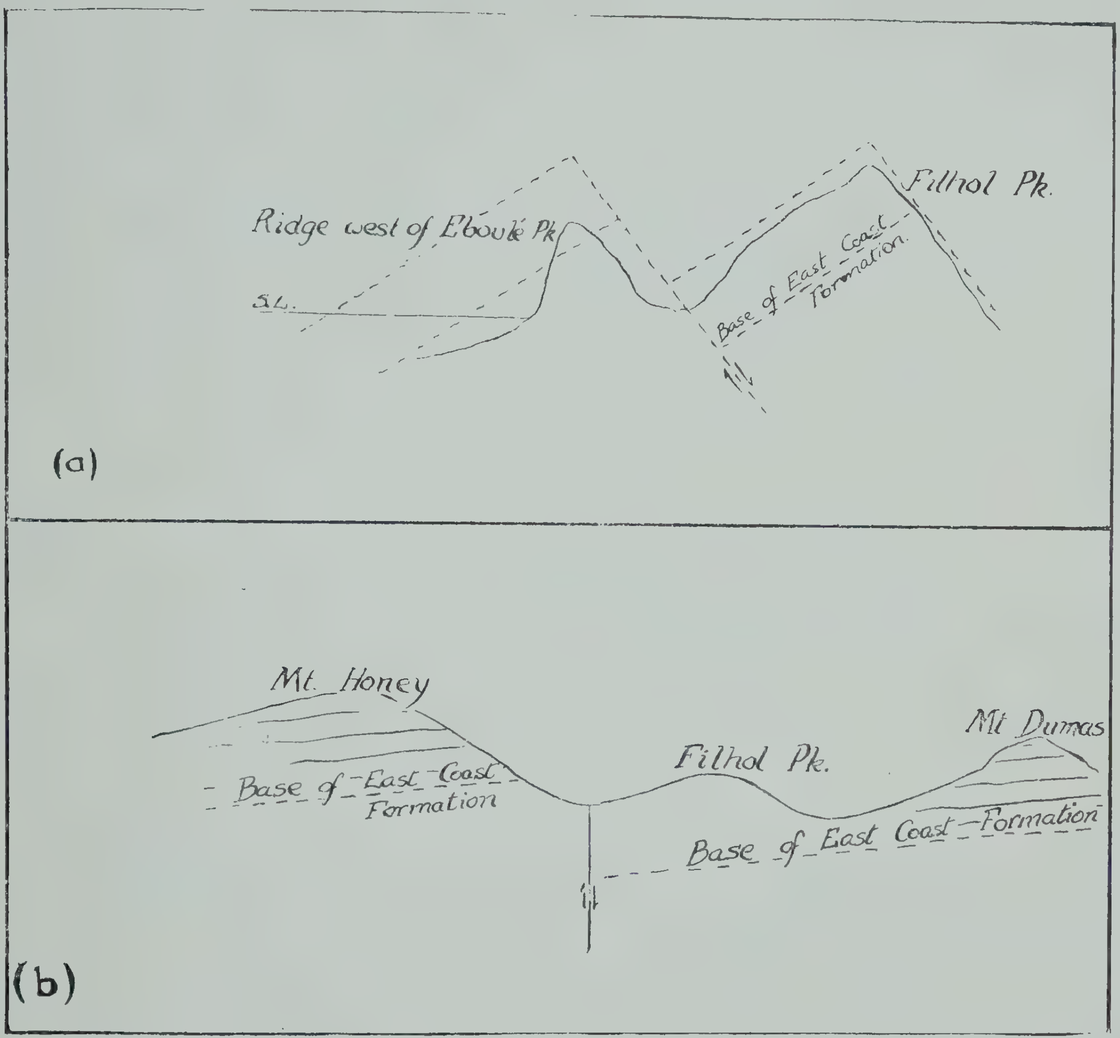

Fig. 7—Diagram illustrating nature of the fault (*a*) south of Filhol Peak, (*b*) east of Filhol Peak.

At the head of Garden Cove, no fault plane is visible, but the complex relationships between brecciated Tucker Cove limestone, Shoal Point breccia, Garden Cove quartz conglomerate, and Complex Point schist suggest the presence of a shatter belt some 200 yards wide (see Sections AB and IJ, Fig. 13). Vertical movement to the extent of 400 ft. must have occurred in order to juxtapose Shoal Point breccia and schist. The age of the movement was possibly post-breccia.

On the coast just south of the headland between Mount Paris and Yvon Villarceau Peak, a limestone block, which outcrops up to 200 ft. above sea-level, has been up-faulted at least 200 ft. into its present position.

Slipping of Coastal Blocks

In the cliff face on the south-west side of Mount Dumas, a lava block has slipped down into the Shoal Point Formation. It appears to be quite a superficial block about 100 ft. in width. In the coastal cliff one mile north-north-west of St. Col Peak,

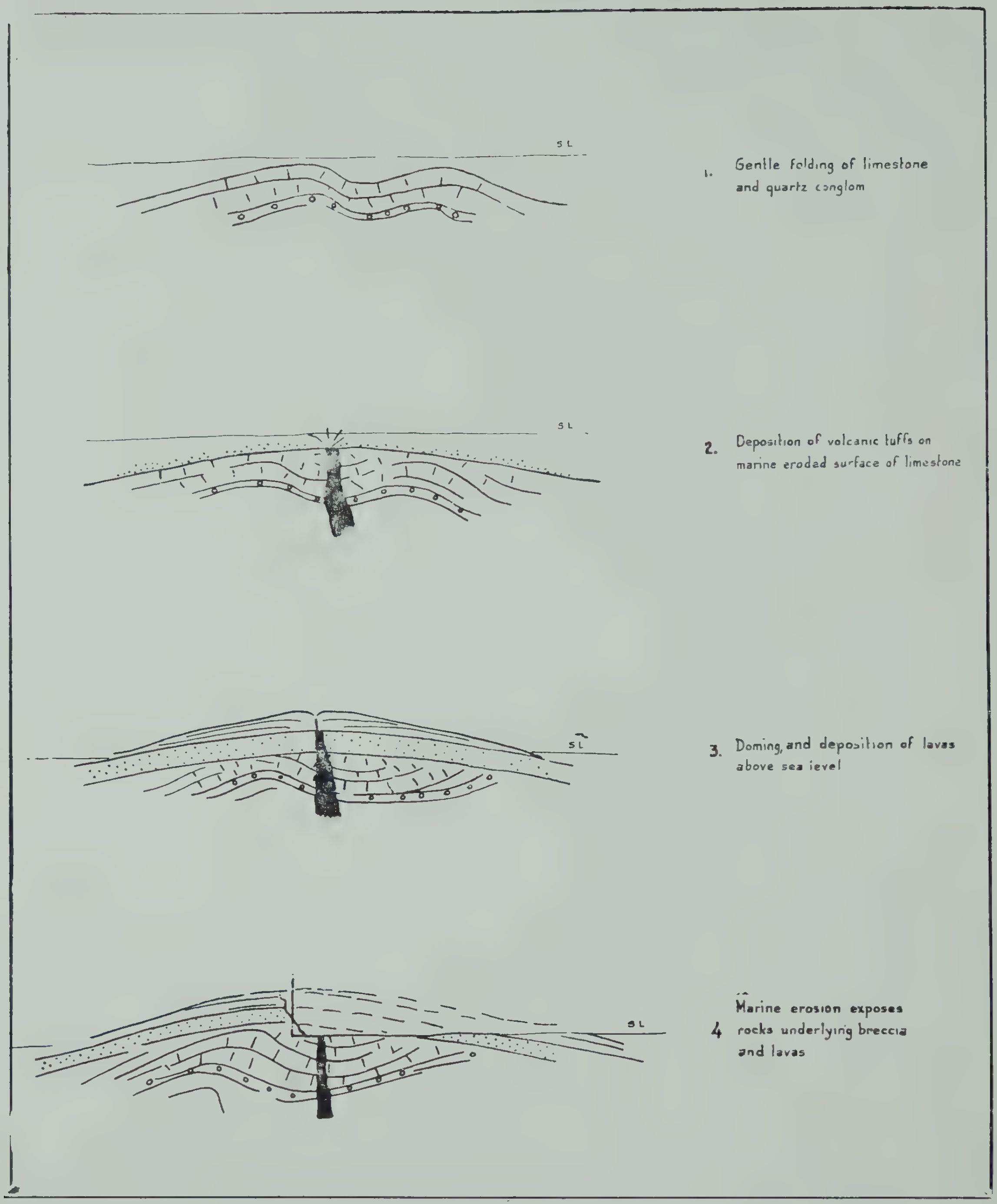

Fig. 8—Diagrams illustrating the geological history of Campbell Island.

an East Coast lava block has slipped down alongside Shoal Point breccia. In one place on the south face of Mount Paris, slipping has lowered the East Coast Formation-Shoal Point Formation contact 150 ft. A small block in the sea cliff a mile east of Courrejolles Point has slipped about 80 ft.

Between Mounts Dumas and Paris, surface slumping of Shoal Point tuffs on a considerable scale has occurred. The slumping was perhaps due to the undermining of a limestone cliff; large displaced limestone blocks are associated with the slumped tuffs.

Displacement Due to Volcanic Activity

The upheaval due to volcanic activity (Plate 7, Figs. 2, 3, and 4) just north of Windlass Bay resulted in considerable displacement of the beds (see Section IJ, Fig. 13). Movement was not along a clear-cut fault.

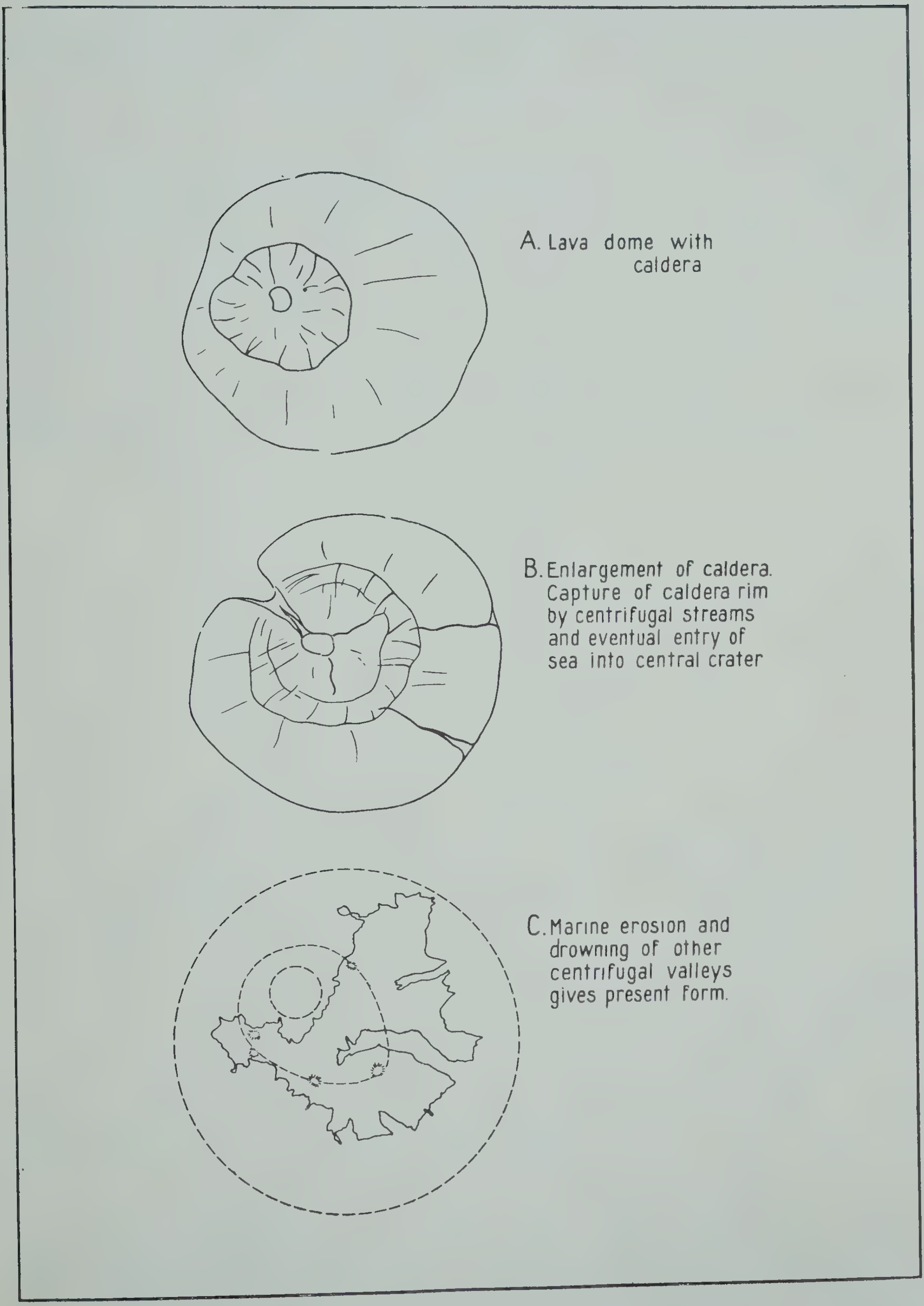

Fig. 9—Diagrams illustrating the post-volcanic history of Campbell Island.

GEOLOGICAL HISTORY

(See Fig. 8)

During the late Cretaceous [New Zealand Piripauan stage (?)], in the vicinity of Campbell Island, a schist (Complex Point Formation) landmass was eroded. Rounded quartz pebbles were derived from the quartz veins penetrating the schist and deposited as lacustrine or estuarine gravels. Their close association with carbonaceous mud and plant fragments testifies to their deposition in shallow water.

Subsequent depression submerged the gravels and carbonaceous deposits (Garden Cove Formation). Most of the adjoining land was also submerged, or had been reduced by erosion to a very low level, because the amount of sediment derived from it was small, and the accumulation of fairly pure limestone was thus facilitated. It is probable that, as the time of greatest accumulation of the limestone, there was very little if any land above sea-level in the vicinity of present-day Campbell Island.

In the middle Oligocene (end of the Whaingaroan stage in New Zealand), the limestone was gently folded and probably elevated slightly above sea-level. At any rate, there was no further sedimentation until the Pliocene. Erosion of the limestone reduced its thicknes in parts, but did not result in the deposition of conglomerates.

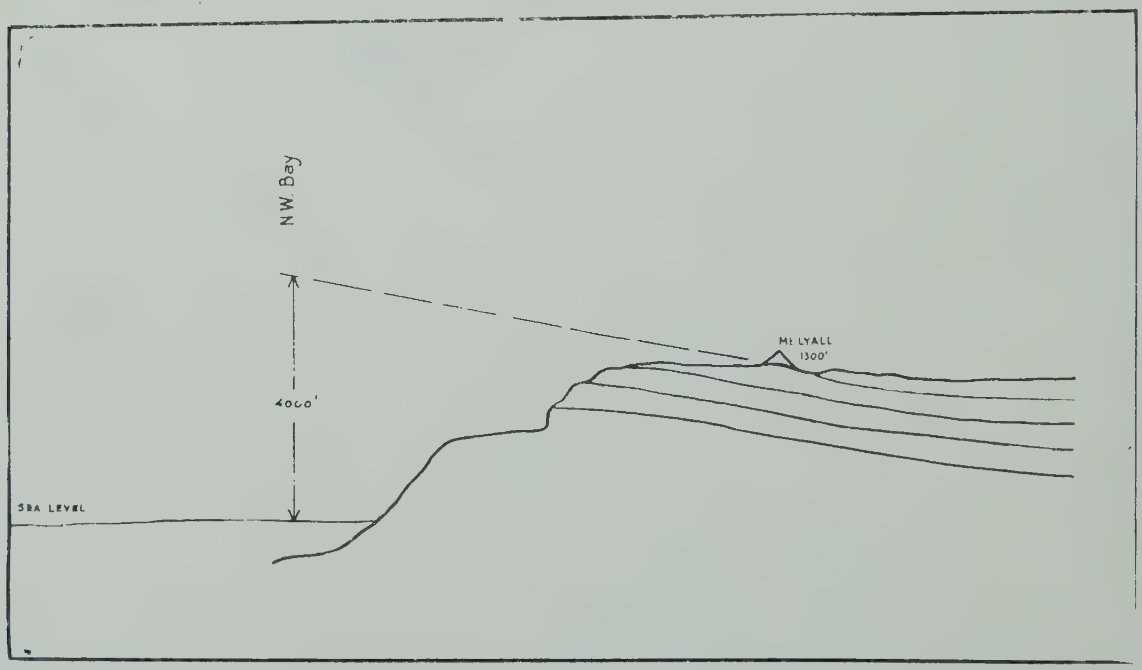

Fig. 10—Diagram showing the westward projection of the flows on Mount Lyall to a point above the presumed crater.

In the early Pliocene (New Zealand Opoitian or Waitotaran stage), explosive vulcanicity broke out and fragmentary material (Shoal Point Formation) was deposited on the limestone surface. If the latter had been above sea-level, it was resubmerged, because the first tuff deposits appear to have been marine. Later, when up-doming and accumulation of sediments had raised the surface above sea-level, terrestrial volcanic breccias were laid down. Evidence suggests that the centre of volcanic activity was an area now occupied by North-West Bay and that Mount Beeman is the neck of a subsidiary cone.

The accumulation of the Shoal Point Formation was interrupted by periods of volcanic quiescence, and parts of the formation exposed above sea-level were eroded, and re-deposited as volcanic pebbles. Coal lenses were formed, inter-bedded with the tuffs.

Later in the Pliocene (?), the nature of the volcanic activity changed and lavas (East Coast Formation) were extruded, though periodic deposition of tuffs continued. All the lava flows appear to have been terrestrial.

The up-doming was due to subterranean pressure of the magma column responsible for the volcanic activity. North-West Bay appears to have been the approximate centre of the uplift, because to-day the oldest rocks are exposed to their greatest height above sea-level in that locality.

At the end of the Tertiary, Campbell Island was probably a fairly symmetrical volcanic cone (Fig. 9): Daly, 1922, considered the amount of marine erosion of St. Helena to indicate a late Tertiary age for that island, and Campbell Island seems to have been eroded to a similar extent. The projection westward of the flows on Mount Lyall to a point above the presumed crater indicates that the peak of this cone was approximately 4,000 ft. above present sea-level (Fig. 10). This, however, cannot be considered the original height of the cone, because there have been considerable pre-glacial and post-glacial vertical land-movements of unknown amount.

Since the cessation of lava extrusion, Campbell Island has been broken by many faults. The gabbro exposed on Mount Menhir and at North-West Bay is considered to have been up-faulted into its present position at this stage. Many of the fractures are not tectonic, but merely bound coastal blocks which have slipped under the influence of gravity.

The subsequent stages of development are illustrated in Fig. 9. Headward sapping of the crater wall by centripetal streams enlarged the crater, resulting in the formation of an erosion caldera (see Cotton, 1944)*; there is no evidence to indicate whether or not collapse or subsidence of the central part of the volcano was in part responsible for the development of the caldera (Williams, 1940). The capture of the crater rim by a large centrifugal stream on the west facilitated rapid deepening of the valley, which, combined with submergence (of unknown amount), enabled the sea to enter the central caldera (see also Marshall, 1915, and Speight, 1917). On the east, smaller valleys were submerged. Marine erosion, particularly on the west, was attacking the coast and developing the present configuration of the island.

There is no evidence to indicate Pleistocene emergence, but owing either to elevation of the land or to regional lowering of temperature, or both (see p. 39), valley glaciers and cirques were formed on Campbell Island and modified the topography. The amount of post-glacial submergence cannot be calculated. Raised beach deposits are exposed 20 ft. above sea-level, and the maximum depth of Perseverance Harbour is 168 ft. (Fig. 1); a probable post-glacial submergence of at least 188 ft. is thus indicated. The height above sea-level of the " Perseverance " valley mouth prior to submergence is not known, however; the full extent of submergence cannot therefore be calculated.

* Cotton's account of the development of an erosion caldera, however, does not imply a stage of erosion by centripetal streams alone.—Ed.

Post-glacial marine erosion of Campbell Island seems to have removed the cirque which supplied the North-East Harbour glacier. Blake (Mawson, 1943) believed that some post-glacial marine erosion had occurred on Macquarie Island, but Mawson disagreed with this contention.

Post-glacial streams in the valleys and "frost-chipping" on the mountain tops have slightly modified the glacial topography.

GEOLOGICAL CORRELATION WITH NEW ZEALAND AND MACQUARIE ISLAND

Campbell Island lies on the edge of a submarine shelf extending south from New Zealand (see Fig. 11). A close relationship between the geology of Campbell Island and New Zealand is therefore to be expected. Although deeper water (Byrd Deep—see Fig. 11) separates Macquarie Island from Campbell Island, the geology also of these two lands appears to be related.

In the New Zealand region, in the late Jurassic or early Cretaceous, Mesozoic sandstones, argillites and conglomerates were strongly folded (Hokonui orogeny) and injected by basic igneous rocks (Bell, 1911, Benson, 1923). Mawson (1911–14) describes altered basic rocks of probable Mesozoic age on Macquarie Island, injected by gabbros and peridotites and strongly folded in the Cretaceous. It is possible therefore that the Campbell Island schists were formed during this time, and that gabbro was injected into them.

In New Zealand, erosion of the folded Mesozoic rocks resulted in the widespread deposition of lacustrine or fluviatile quartz conglomerates or "quartz drifts" (Morgan, 1921, Macpherson, 1937); these constitute the base of the Tertiary sedimentary sequence in many places. The similar basal quartz conglomerate on Campbell Island, unconformable on the folded older rocks, indicates a sequence of events almost identical to that in New Zealand.

"Notocene" (Thomson, 1917, p. 408) is the name given to the Upper Cretaceous and Tertiary sediments of New Zealand deposited subsequent to the Hokonui orogeny and terminated by the Kaikoura orogeny at the end of the Tertiary. The Notocene transgression commenced at different times in different places. In the vicinity of Campbell Island, Notocene sedimentation commenced at the end of the Cretaceous (see Table). The carbonaceous mudstone exposed on Campbell Island can be correlated with similar deposits near the base of the Notocene in many parts of New Zealand (see Finlay and Marwick, 1940). The argillaceous limestones which followed in the Campbell Island region closely resemble in form and composition some of the New Zealand limestones of corresponding age (see Speight and Wild, 1918, for a description of the Amuri limestone, New Zealand), and also that exposed on Macquarie Island (Mawson, 1911–14). The $CaCO_3$ percentage of the Macquarie Island Tertiary lithographic limestone is 88·66 (Mawson, 1911–14), compared with 84·5% and 85·9% for the Campbell Island limestone and the Amuri limestone, New Zealand, respectively. Marshall (1907), Park (1925), and Gregory (1930) mentioned the probable correlation of the limestones of New Zealand and Campbell Island.

Only a few of the localities providing evidence for the widespread volcanic activity in New Zealand during the Pliocene have been indicated in the table. In the middle of the North Island of New Zealand, in the Pliocene, pumice showers were followed by the extrusion of andesitic lavas and scoria; this activity (unlike that which occurred in the Campbell Island region) has continued to the present day. Pliocene vulcanism in New Zealand was the culmination of intermittent volcanic activity occurring during the earlier Tertiary (Uttley, 1918). On Macquarie Island, basaltic and andesitic conglomerates, breccias and lavas are associated with the Tertiary lithographic limestone (Mawson, 1943).

The post-volcanic faulting of Campbell Island is possibly to be correlated with the Kaikoura orogeny in New Zealand, but many of the fractures on Campbell Island appear to be due to gravitational slipping of segments of the coastal cliffs.

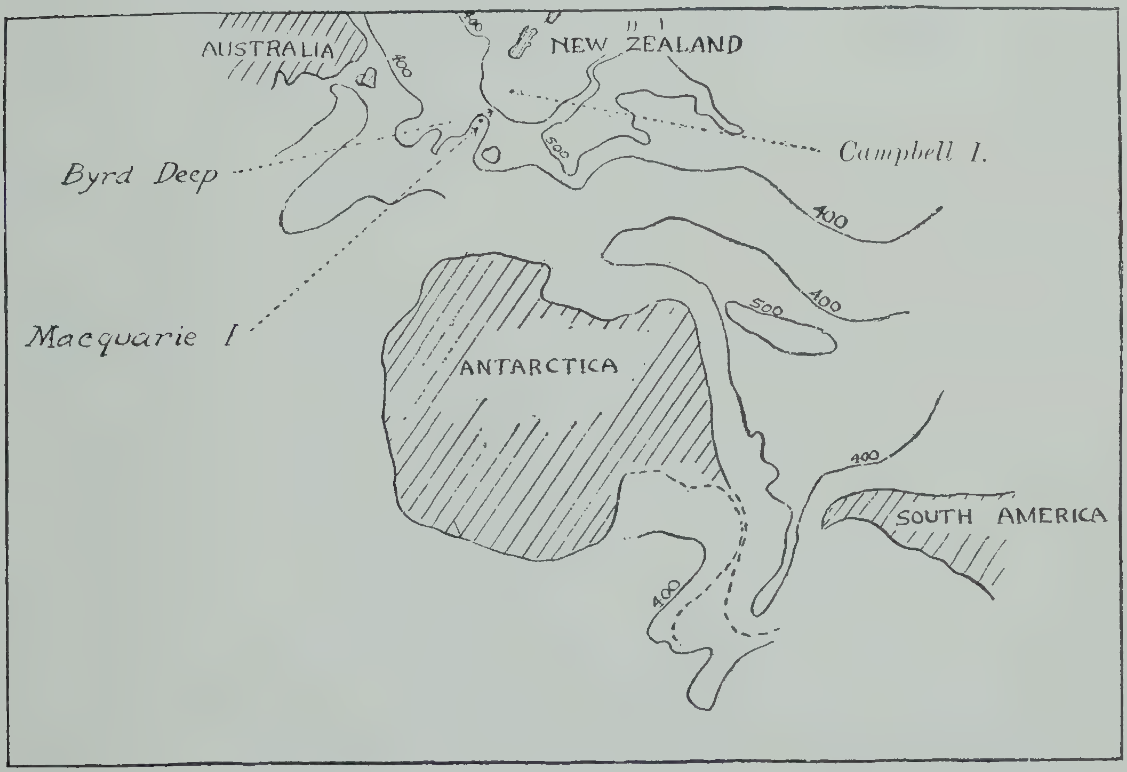

Fig. 11—Map of Antarctica and environs showing ocean bottom contours (metres below sea-level). (After Sverdrup, Johnson and Fleming, 1942, Fig. 4.)

GLACIATION IN THE SOUTH-WEST PACIFIC

There appear to have been small valley glaciers and cirques on Campbell Island, but there is no proof that the island was covered by a continuous ice sheet.

Park (1910) strongly contended that there had been a continuous Pleistocene ice sheet extending from the Antarctic continent to the southern part of New Zealand, and thus covering Campbell Island. Most other writers (Hutton, 1893, Marshall, 1910, G. M. Thomson, 1910, Trechmann, 1917, Speight, 1939) have disagreed with this hypothesis, and have maintained that Pleistocene glaciation in the South-West Pacific resulted merely in the formation of valley glaciers, many of which still exist, although reduced considerably in size.

As the part cause of the Pleistocene reduction of temperature in New Zealand and its sub-Antarctic islands, the majority of writers (Park, 1910, Marshall, 1910, Adkin, 1911, Griffith Taylor, 1926, Ferrar, 1928, Williams, 1936, Speight, 1939) have postulated elevation of the land, though Marshall (*op. cit.*), at least, considered such uplift of little importance. An elevation of 2,000 ft. would be necessary to bring the lowest cirque on Campbell Island (200 ft. above sea-level) within the 32°F. required for maximum nivation (Griffith Taylor, *op. cit.*). There is no evidence to indicate whether or not Campbell Island has been lowered 2,000 ft. since glacial times; the amount of submergence is not known. Therefore the relative importance of regional lowering of temperature and greater elevation of the land as causes of glaciation on Campbell Island cannot be stated.

There is evidence for more than one Pleistocene glacial advance in New Zealand. J. Henderson (1931), Hutton (quoted by Henderson), and Willett (1939) concluded that there were two periods of ice advance, and H. Wellman (personal communication) has recently found evidence for four advances on the west coast of the South Island of New Zealand. In Tasmania, Lewis (1933) has found evidence for three glacial epochs. The writer, however, cannot with confidence sub-divide the Pleistocene glaciation of Campbell Island.

TECTONIC RELATIONSHIPS OF CAMPBELL ISLAND

The similarity between the late Cretaceous and early Tertiary geology of New Zealand, Campbell Island, and Macquarie Island extends through Edward VII Land and Graham's Land to South America, and many writers (Chilton, 1909, Griffith Taylor, 1914, Benson, 1921, Du Toit, 1937, Wade, 1941) have postulated the existence of land connections to explain the similarities. The evidence points to the existence of a late Cretaceous and early Tertiary geosyncline (the "Samfrau" geosyncline of Du Toit) extending from New Zealand to South America (Wade, *op. cit.*), uplifted at intervals during the Tertiary as a "Pacific" marginal fold feature (Griffith Taylor, 1914), and later broken by subsidence along faults (Gregory, 1930). Volcanic activity has been, and is, associated with this marginal fold.

Fig. 12 illustrates the folded geosynclinal sediments represented by Edward VII Land and New Zealand, separated from the faulted eastern boundary of South Victoria Land (Ferrar, 1914) and faulted east coast of Australia respectively by the Ross Sea-Tasman Sea graben. It is noteworthy that in the South-West Pacific there are thus two major tectonic features, the "Atlantic" coast feature of eastern Australia and South Victoria Land, and the "Pacific" marginal fold feature (Du Toit's "Antarctades"), of which Campbell Island is part.

Hobbs (1923) stated that the marginal fold in the vicinity of New Zealand was the result of eastward underthrusting of the Tasman Sea graben.

Du Toit (*op. cit.*) considered the fold features of the South Pacific and the distribution of land to be the result of horizontal drifts; Bailey Willis (1928) maintained that all horizontal movement is impossible and that all land connections, particularly in the South-West Pacific, are due to broad, widely distributed, vertical movements—broad up-domings and submergences.

FIG. 12—Map of Antarctic Regions showing principle tectonic features. (Compiled from Griffith Taylor, 1914, Du Toit, 1937, Wade, 1941.)

APPENDIX TO PART I

Chemical Analyses of Lignites, Tuff, and Limestone

By Dominion Analyst,
Dominion Laboratory, New Zealand

1. Lignites

A. Lignite (weathered) from top of cliff just north of Eboulé Peak.
B. Lignite (unweathered) from top of cliff just north of Eboulé Peak.
C., D., E., F., G. Lignites from just above sea-level at tip of peninsula bounding west side of Monument Harbour.
H. Lignite from west-coast cliff one mile south of Courrejolles Point.

Prox. Analysis (on air dry coal)

	A	B	C	D	E	F	G	H
Moisture	16.5	21.2	21.9	21.9	22.4	21.6	21.4	10.4
Vol. matter	51.7	42.1	39.2	38.9	39.0	39.4	38.7	13.0
Fixed C	26.9	30.7	29.3	29.3	29.1	28.7	29.4	5.4
Ash	4.9	6.0	9.6	9.9	9.5	10.3	10.5	71.2
S	0.5	0.5	1.4	1.2	1.2	1.2	1.4	0.3
Cal. value (B.Th.U./lb)	8460	7950	7320	7170	7070	7310	7250	2250

Ult. Analysis (calc. to dry ash-free coal)

	A	B	C	D	E	F	G	H
C	62.3	64.4	64.6	64.4	63.9	64.2	65.2	64.1
H	5.6	5.2	5.0	5.0	4.9	5.1	4.9	5.8
N	0.6	1.5	1.3	1.2	1.2	1.2	1.3	2.3
S	0.6	0.7	2.1	1.8	2.1	1.7	2.8	1.8
O	30.9	28.2	27.0	27.6	27.9	27.8	26.8	26.0

Analyst's Comments

Specimen A has a higher volatile content and contains more oxygen on a dry ash-free basis than specimen B. Specimens A and B have a sulphur content of about 0·5%, and should be compared with the specimens from Monument Harbour, which have a sulphur content of about 1·3%. If the samples are at all representative of the seams from which they were taken this difference in sulphur content will indicate different conditions of deposition. Specimen H contains a very small amount of lignite which is nevertheless similar in ultimate analyses to the other samples.

2. Tuff from cliff one mile west of Mount Dumas

Fe_2O_3	8·2%
Al_2O_3	13·5%
K_2O	0·9%

Analyst's Comment

The sand contains also: MnO 0·3%, TiO_2 2·2%, $CaCO_3$ 6·0%. It appears that the potash may come from clay or felspar and the iron from ilmenite.

3. Mixture of Limestone Samples from several localities on the island.

$CaCO_3$	84·5%

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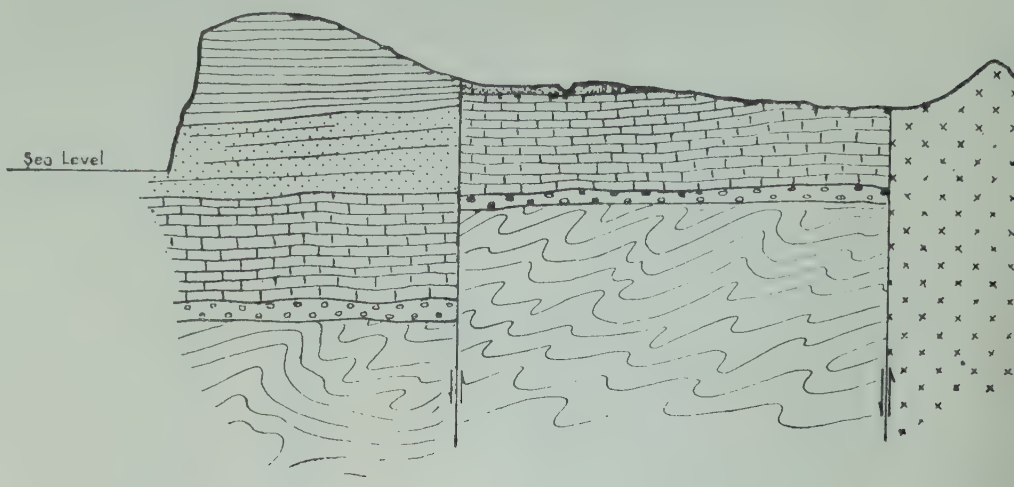
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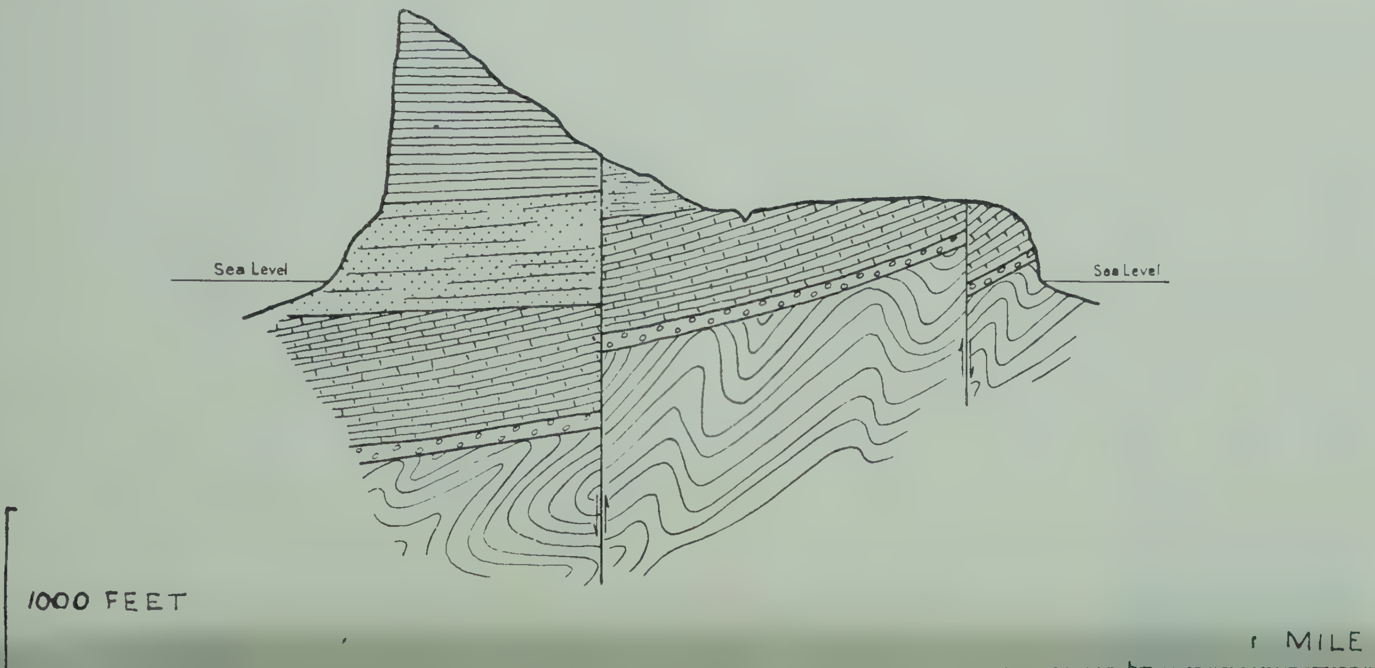

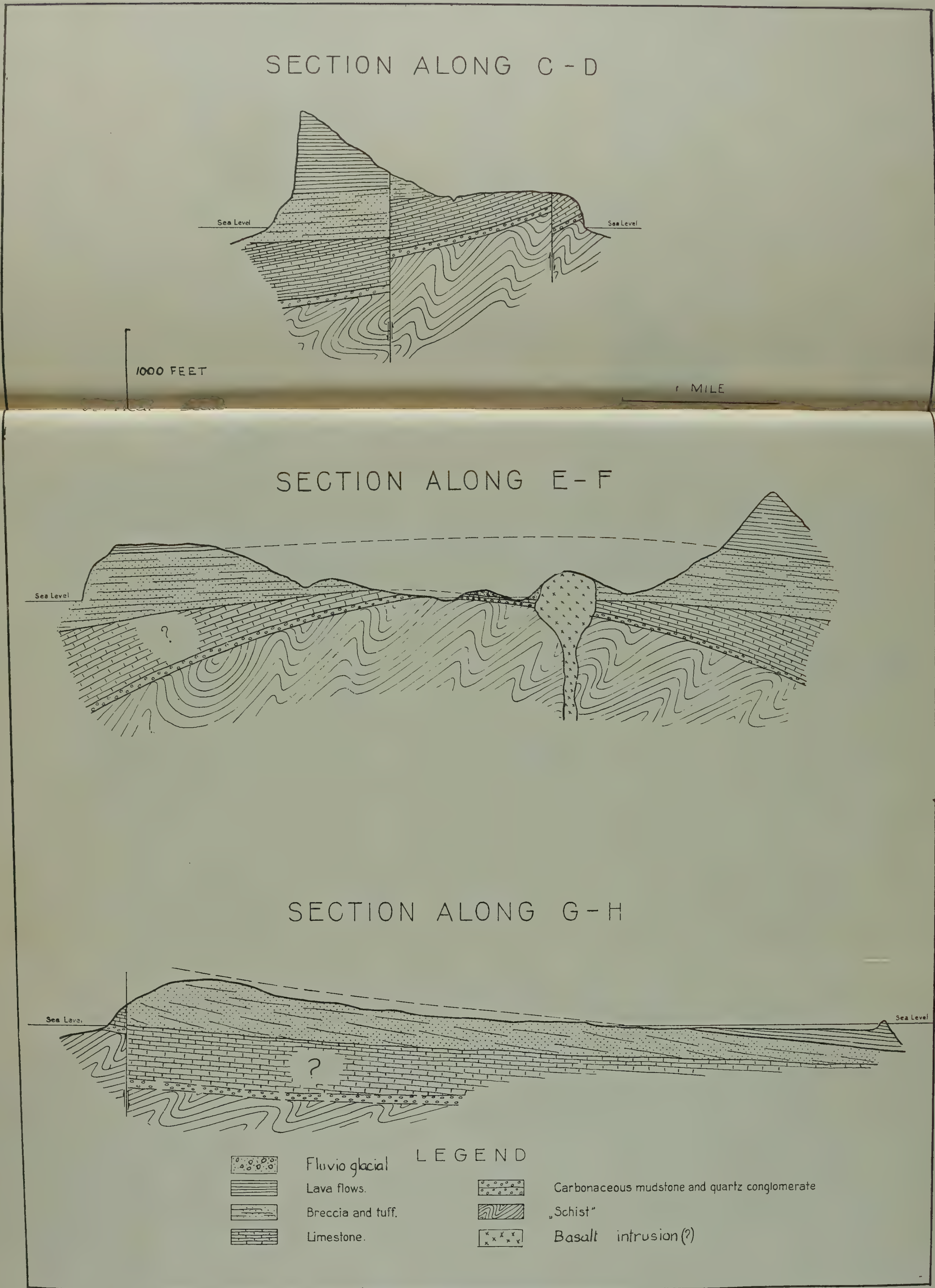

Fig. 14—Geological sections CD, EF, and GH.

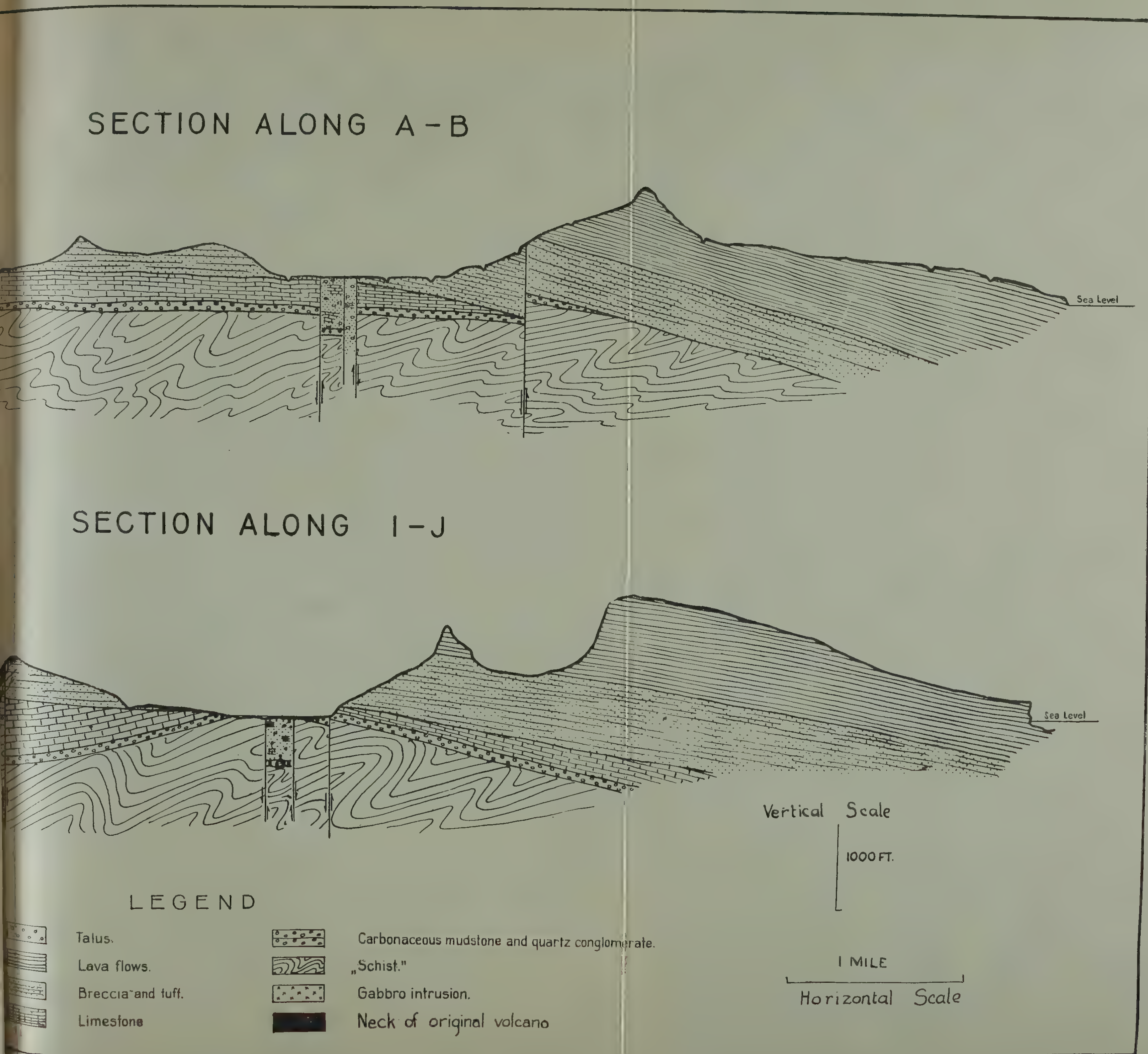

FIG. 13—Geological sections AB and IJ.

PART II

FOSSIL FORAMINIFERA FROM CAMPBELL ISLAND

By H. J. Finlay

Micropalaeontologist, N.Z. Geological Survey

Twenty-eight samples were washed and examined for foraminifera; unfortunately, all but five were unsuitable material and devoid of fauna. Except for the first two, the five were not in sequence, and the results from these isolated samples merely show that at least five different age-formations exist on the island. They are as follows (from the lowest upwards):—

(1) F.6404. Carbonaceous mudstone, west side of Camp Cove, Perseverance Harbour.

Microfauna of numerous radiolaria and a single foraminiferal species, *Gaudryina whangaia* Fin. This species, however, is limited to the Teurian Stage in the uppermost Cretaceous of New Zealand, just above the Piripauan, corresponding to the Waipara Greensands.

(2) F.6406. Speckled soft argillaceous limestone, just above carbonaceous mudstone, Camp Cove, Perseverance Harbour.

Microfauna mainly calcareous, but badly battered. Specimens mostly broken and with pitted surface, but the following could be identified:

Bolivinopsis spectabilis (Gryzb.)
„ *cubensis* (C. & B.)
„ *compta* Fin.
Vulvulina espinosa Fin.
Clavulinoides instar Fin.
Palmula aff. *bivium* Fin.
Vaginulinopsis waiparaensis (Fin.)
Nodosaria cf. *affinis* Reuss
Zeauvigerina zelandica Fin.
Pseudouvigerina aff. *wilcoxensis* Cush. & Pont.
Bulimina pupula Stache
Bulimina cf. *striata* d'Orb.
„ *serratospina* Fin.
Buliminella browni Fin.
Nonion maoricum (Stache)
Anomalina visenda Fin.
Anomalinoides eoglabra (Fin.)
Parrella sp.
Nuttallides carinotrumpyi Fin.
Cibicides collinsi Fin.
„ n.sp.
Globorotalia n.sp. aff. *crater* Fin.
Globoquadrina primitiva Fin.
Also Radiolaria

This is unquestionably a Lower Eocene fauna, but the absence of certain key species makes its exact position uncertain. It is probably not as young as the Stage represented by the Kurinui beds at Hampden (Heretaungan), but may belong to the stage just below (Mangaorapan); it is equivalent to the faunas found in the Middle Waipara just above the Waipara Greensands. It may also be the same age as the Chatham Island *Notostrea tarda* bed at Tioriori, which contains *Gaudryina reliqua* and an *Elphidium* close to *hampdenensis*, and is considered Mangaorapan.

(3) F.6424. Cliff, ½ mile north-east of Windlass Bay; from scree associated with macro-fossils.

Fairly well preserved micro-fauna, with large specimens (*Nodosaria,* etc.) occasionally showing on the surface of the hand-specimens.

Plectina agrestior Fin.
Karreriella chilostoma (Reuss)
Robulus n.sp. aff. *formosus* Cush.
„ aff. *cultratus* Mont.
Vaginulinopsis hochstetteri (St.)
Marginulinopsis spinobesa Fin.
Nodosaria aff. *callosa* Stache
Bulimina bortonica Fin.
Cassidulina subglobosa Brady
Allomorphina aff. *trigona* Reuss
Nonion aff. *maoricum* (Stache)
Anomalina visenda Fin.
Anomalina aotea Fin.
„ *semiteres* Fin.
Gyroidinoides prominulus (Stache)
Eponides ecuadorensis G. & M.
Nuttallides subtrumpyi Fin.
Cibicides parki Fin.
„ *collinsi* Fin.
„ n.spp.
Globoquadrina primitiva Fin.
Globigerina turgida Fin.
Discorbis appositus Fin.

This is a typical Bortonian (Middle Eocene) fauna, just as occurs in the zone of molluscan fossils at Hampden beach. In general facies it is especially like several faunas from the lower part of the "Amuri Limestone," e.g., F.5662, Conway Mouth limestone with flints, 50 ft. above base; F.5606, Mount Highfield chalk marl.

(4) F.6403. Tucker Cove limestone (collected by C. A. Fleming, January, 1943). Large, well-preserved fauna, with many index species.

Bolivinopsis cubensis (C. & B.)
Vulvulina bortonica Fin.
Hagenowella ? sp.
Vaginulinopsis hochstetteri (St.)
Nodosaria cf. *affinis* Reuss
Dentalina n.sp.
Chrysalogonium striatissimum (St.)
Stilostomella pomuligera (St.)
„ *antipoda* (St.)
„ cf. *challengeriana* (Thal.)
Gumbelina ototara Fin.
Bolivina n.sp.
Uvigerina bortotara (Fin.)
Trifarina bradyi Cush.
Bulimina truncanella Fin.
Nodosarella salmojraghii (Mart.)
Cassidulina subglobosa Brady
Pullenia quinqueloba (Reuss)
„ *bulloides* (d'Orb.)
Nonion maoricum (Stache)
„ n.sp. aff. *maoricum* (St.)
Anomalina aotea Fin.
Anomalina semiteres Fin.
Anomalinoides fasciatus (Stache)
„ *eosuturalis* (Fin.)
„ *eoglabra* (Fin.)
Gyroidinoides prominulus (Stache)
Rotaliatina sulcigera (Stache)
Eponides ecuadorensis G. & M.
Parrella sp.
Alabamina tenuicarinata (C., P. & C.)
Pulvinulinella n.sp.
Cibicides parki Fin.
„ *collinsi* Fin.
„ aff. *novozelandicus* (Karr.)
„ aff. *robertsonianus* (Brady)
„ *thiara* (Stache)
„ aff. *maculatus* (Stache)
„ n.sp.
Discorbis appositus Fin.
Globoquadrina aff. *primitiva* Fin.
Globorotalia cf. *subcretacea* (Lornn.)
Globigerinoides index Fin.
Sphaeroidina n.sp.

This is a Kaiatan fauna (Lower Upper Eocene), somewhat similar to those found in the Burnside Marl and the top part of the Hampden section at Lookout Bluff. The presence of *Anomalina semiteres* indicates that it is low in the Kaiatan, as this species is rare outside of the Bortonian.

(5) F.6402. Penguin Bay, $1\frac{1}{2}$ miles north of Mount Paris. Argillaceous limestone interbedded (as the result of faulting) with tuffs.

Small but well-preserved microfauna, ecologically similar to F.6403.

Vulvulina granulosa Fin.
Stilostomella pomuligera (St.)
Chrysalogonium striatissimum (St.)
Uvigerina maynei Chapman
Bulimina truncanella Fin.
Cassidulina subglobosa Brady
Pullenia quinqueloba (Reuss)
„ *bulloides* (d'Orb.)
Nonion aff. *maoricum* (Stache)
Anomalinoides fasciatus (Stache)
Gyroidinoides prominulus (Stache)
Eponides ecuadorensis G. & M.
Cibicides n.sp. of Oxford Chalk
„ *thiara* (Stache)
„ aff. *robertsonianus* (Brady)
Laticarinina halophora (Stache)
Globigerina angillpora Stache

This fauna, though somewhat like a poor representation of F.6403, lacks all of its Kaiatan key species, and the presence of *U. maynei* makes it certain that the horizon is either Whaingaroan or low Duntroonian. Because of the absence of *Rotaliatina* and the smallness of the fauna, it is not possible to refer it to either with certainty, but a poor facies of Whaingaroan (Lower Oligocene) may be suggested.

PART III

THE FOSSIL FAUNA OF THE CAMPBELL ISLAND BRECCIAS

By C. A. Fleming
N.Z. Geological Survey

ABSTRACT

The fossil mollusca and brachiopoda of the Campbell Island breccias are listed and described as a basis for discussion of the age of the bed which is considered early Pliocene. Anomalies and difficulties in correlating an insular fauna are discussed. The affinities of the fossil mollusca and brachiopoda are with those of the New Zealand region, of which Campbell Island is to be considered a peripheral part. The temperature facies of the mollusca indicates more temperate oceanographic conditions than those at present prevailing.

INTRODUCTION

Fossils from the Campbell Island volcanic breccias were described by Filhol (1885) and Marshall (1909) and each of these writers described a new species from them (*Walheimia campbellica* Filhol and *Glycymeris chambersi* Marshall). The collections made by Mr. R. L. Oliver in 1944 were submitted to the writer for study and report.

FAUNAL LIST OF CAMPBELL ISLAND BRECCIAS

TABLE I

	A	B	C	D	E
MOLLUSCA					
Grandaxinea chambersi (Marshall)		×			×
Chlamys cf. *delicatula* (Hutton)	×	×			×
Lima robini n.sp.	×	×			×
Limatula maoria Fin.	×				×
Modiolus altijugatus Marw.		×			×
Venericardia haskelli n.sp.	×	×			×
Longimactra n.sp. aff. *elongata* (Q. & G.) ..	×				
Tawera aff. *subsulcata* (Suter)	×				
Notocorbula n.sp.					×
Austrosassia n.sp.	×				
BRACHIOPODA					
Tegulorhynchia n.sp. cf. *antipoda* Thomson ..		×	×		
,, cf. *squamosa* (Hutton) ..		×			
Terebratella n.sp. aff. *sanguinea* (Leach) ..			×		
Liothyrella cf. *gravida* (Suess)		×			
Neothyris campbellicus (Filhol)	×	×		×	×
Neothyris n.sp.	×				
Terebratulina suessi (Hutton)	×				
ECHINODERMATA					
Eupatagus sp.		×			

LOCALITIES:

A. Breccia, Shoal Point, Perseverance Harbour, Campbell Island (Field Nos. 165, 118–128, 305).

B. Band in breccia composed of fragments of calcareous marine organisms, 240 ft. above sea-level, cliff west of Mount Dumas (Field Nos. 75–79 and 256). Loose blocks of breccia below west cliff of Mount Dumas, Campbell Island (Field No. 255).

C. Fossils from band in breccia, composed of fragments of calcareous organisms, approximately 300 ft. above sea-level, cliff on S.W. side of Mount Paris, Campbell Island (Field No. 86) and loose block below S.W. cliff of Mount Paris (Field No. 89).

D. Calcareous band in breccia, sea-cliff halfway between Mount Azimuth and Courrejolles Point, Campbell Island (Field No. 275).

E. Breccia, just above sea-level, south coast of Campbell Island, halfway between Mount Dumas and Mount Eboulé (Field Nos. 296 and 303).

SYSTEMATICS

PELECYPODA

Glycymeridae

Grandaxinea chambersi (Marshall)

Glycymeris chambersi, Marshall, 1909. *The Subantarctic Islands of New Zealand.* Art. 29, p. 701.

Glycymeris chambersi Marshall: Marwick, 1923. *Trans. N.Z. Inst.,* Vol. 54, p. 67, Pl. 1, Fig. 7.

The best specimens come from loose blocks below the west cliff of Mount Dumas which has fallen from an undiscovered outcrop 200 ft. or 300 ft. above sea-level. They are probably exact topotypes of Marshall's species, of which the types were " found in breccia on the south coast by Mr. Chambers."

Marwick (1923, p. 67) re-examined the type material and reaffirmed its distinctness from related species. In its fine pattern of chevrons on the area, *chambersi* agrees with Miocene *Grandaxinea,* of which named forms are *aucklandica* Powell (Altonian stage), *finlayi* Laws (Lillburnian) and *monsadusta* Marwick (Waiauan) rather than with the Upper Miocene (Tongaporutuan) to Recent *G. laticostata* (Q. & G.) and its relative *G. wairarapaensis* Powell, which have a coarser pattern of fewer chevrons. Taranaki specimens from Uruti (G.S. 1139) are scarcely to be separated from *laticostata. G. chambersi,* therefore, with its fine chevrons, has its affinities in the middle Miocene, and, since the rest of the Campbell Island breccia fauna seems younger than that, that type of *Glycymeris* apparently persisted longer there than on the mainland of New Zealand. This suggests a certain degree of insular isolation dating from at least the middle Miocene.

Grandaxinea is not represented in the Recent fauna of the Sub-antarctic Islands, the most southerly published record being Foveaux Strait (Powell, 1939, p. 212): it is recorded from the Pliocene (Nukumaruan) at the Chatham Islands (Marwick, 1928, p. 443), where it persists in the Recent fauna.

Chlamys aff. **delicatula** (Hutton)

Poorly preserved *Chlamys* are not uncommon in the breccias from Shoal Point and Mount Dumas. They are chiefly casts with little shell material remaining. The shells range from 10 to 36 mm. in height; small right valves have little inflation, left valves are moderately inflated. Smaller examples have 17 to 22 primary ribs, straight sided and flat topped, with few weak scales. On some specimens, with interspaces wider than the ribs, sculptured (in one well-preserved specimen) by conspicuous fine regular intercostal concentric lamellae. Larger specimens show the development of secondary riblets about 18 mm. from the umbo, and in well-preserved casts of shells about 25 mm. in height, sculpture consists of primary ribs, very slightly scaly, with much weaker scaly secondary riblets close on either side of the primaries.

In the *radiata-geminata* species group, which frequently shows paired secondaries flanking the primary ribs, the primaries are weaker and more numerous and break up into secondaries at a much earlier stage than in the Campbell Island fossils. Among Recent New Zealand *Chlamys* possession of about 20 strong regular primary ribs on small shells is characteristic of the species *dichroa* Suter, *campbellica* Odhner, and *kiwaansis* Powell. Of these, *campbellica* and *dichroa* have strong intercostal lamellation, but the latter is apparently specialized, with very little inflation, and need not be further considered. The Recent *C. campbellica* is represented in the Pliocene by *delicatula* Hutton, *seymouri* and *titirangiensis* Marwick, and comparison of the Campbell Island fossils with a series of middle Pliocene *delicatula* shows them to be very similar, though perhaps separable with better material. Pre-Pliocene *Chlamys* seldom reach the size of the largest Campbell Island specimens (height 36 mm.). *C. chathamensis* (uppermost Miocene or lowest Pliocene of Chatham Islands) links the Pliocene forms morphologically with a Miocene and Oligocene group of species which includes *compitum* Marwick, *oamarutica* Murdoch,* and *mercuria* Marwick, which are superficially similar, in the number, strength and spacing of the ribs, to the smaller Campbell Island shells, but which do not exceed 26 mm. in height and mostly lack regular intercostal lamellation.

The Campbell Island form is thus closest to the Pliocene (Waitotaran-Nukumaruan) *C. delicatula* Hutton, but since that species appeared in New Zealand as an immigrant from the south (Fleming, 1944, p. 209) this does not necessarily indicate a Pliocene age for the Campbell Island breccias.

Limidae

Lima robini n.sp. (Plate 9, Figs. 1, 6)

Lima colorata Hutton: Marshall, *The Subantarctic Islands of New Zealand*, p. 701. (Not of Hutton.)

Shell large, massive, thick, moderately inflated. Anterior and posterior margins meeting at almost 90° at low beaks. Sculpture: 16 to 18 strong radial ribs, triangular in section, their summits narrowly rounded, with broad concave interspaces appreciably wider than the ribs. Fine growth lines crossing ribs and interspaces and coarser on ears and margins of disc. Posterior ear moderate with two radial ridges; anterior ear weak, with growth lines only. Hinge massive, without tubercles; submargin with strong growth lines, radials weak or absent. The sculptural detail is best shown by an incomplete paratype.

Height 122 mm.; length 115 mm.; thickness (1 valve) 28 mm. (holotype).

Localities: Breccia on coast halfway between Mount Dumas and Mount Eboulé, 40 ft. above sea-level. (Field No. 303, holotype.) Shoal Point, Perseverance Harbour, below west cliff of Mount Dumas.

Most of the Miocene New Zealand species of *Lima* can be be grouped with *L. colorata* Hutton, and that lineage continues into the late Miocene as *L. watersi* Marwick (Tongaporutuan and Kapitean) and persists in the Recent fauna as *L. zelandica* Sow. The *colorata* group has broadly rounded or flat-topped straight sided ribs, with interstices of equal or less width. The continuity of the *colorata-zelandica* lineage is broken in the early Pliocene by the occurrence (exclusively so far as is known, but data are meagre) of a *Lima* with wide-spaced narrowly rounded ribs and concave interspaces. This is *L. waipipiensis* Marshall and Murdoch, from the lower Waitotaran beds of North-West Wellington. *Lima vasis* Marw. (? Opoitian), from the Chatham Islands, is in several ways intermediate between *waipipiensis* and the *colorata* group, having wide interspaces between the ribs, which are, however, broadly rather than narrowly rounded. *L. robini* is unquestionably closer to *waipipiensis* than to any other species, but has a wider apical angle, reaches a larger size, and has a greater number of radial ribs.

* Subsequent examination of the holotype of *oamarutica* has shown it to be a young *Hinnites*.

Fig. 1—*Lima robini* n.sp., paratype, × [illegible].

Fig. 2—*Venericardia haskelli* n.sp., paratype, × $\frac{7}{8}$.

Fig. 3—*Venericardia haskelli* n.sp., holotype, × $\frac{5}{6}$.

Fig. 4—*Venericardia haskelli* n.sp., holotype, × 1.1.

Fig. 5—*Venericardia haskelli* n.sp., paratype, × $\frac{7}{8}$.

Fig. 6—*Lima robini* n.sp., holotype, × 1.1.

Plate 9

Many recent *Lima* are tropical, but large species extend into the temperate Atlantic (*L. excavata* Chem., Norway). Although the Recent *L. zelandica* is listed by Powell (1937, p. 56) as confined to the Forsterian Province there are Moriorian (Chatham Island) specimens in the Geological Survey collection, but there are no records from the Subantarctic Islands of New Zealand.

The species is named after its collector, Mr. Robin L. Oliver.

Limatula cf. **maoria** Finlay

Casts of three shells, up to 15 mm. in length, have the outline and fine ribbing of *maoria* and are not like *L. morioria* Marw. (Lowest Pliocene, Chatham Islands) nor named species from older beds. *L. maoria* is a recent species found throughout the New Zealand region and extending back, as a fossil, at least to the Opoitian stage of the New Zealand Pliocene.

Mytilidae

Modiolus altijugatus Marwick

In view of the variability of species in this genus, the Campbell Island specimens are so close to the types of *altijugatus* that they must be considered conspecific.

The species was described from Tongaporutuan beds and has been identified from still lower in the Upper Miocene at Hurupi Creek and from uppermost Miocene (Kapitean) in the Ormond Series (Marwick, 1931, p. 66). The Pliocene to Recent *M. aerolatus* Gould has not been seen in beds older than the Opoitian stage.

Carditidae

Venericardia haskelli n.sp. (Plate 9, Figs. 2–5)

Venericardia australis (Q. & G.) Marshall. *The Subantarctic Islands of New Zealand,* p. 701.

Shell very similar to *V. purpurata* Desh. (Recent, New Zealand), but reaching a larger size (up to 59 mm.), more rectangular in outline and more massive, with a heavier hinge. Sculpture of 19 to 22 strong rounded radial ribs, weakly tuberculate or imbricate. Left hinge differing from that of *purpurata* in the width of the socket between the lunular edge and the cardinal tooth, which is narrow in relation to the strength of the hinge; lunular margin almost vertical. Right hinge much as in large *purpurata.*

Height 42 mm.; length 54 mm.; inflation (1 valve) 19 mm. (holotype, right valve). Height 36 mm.; length 47 mm.; inflation 15·5 mm. (paratype, left valve). Height 47 mm.; length 59 mm. (largest paratype).

Locality: South coast, halfway between Mount Dumas and Mount Eboulé [Field No. 303] (type) and Shoal Point, Perseverance Harbour, Campbell Island.

At the end of the Miocene *Venericardia* species related to the Recent *V. purpurata* and *difficilis* Desh. appeared cryptogenetically in New Zealand, replacing the *V. subintermedia* group which is not known later than the Waiauan stage. *V. perscrupulosa* Marwick, Burnt Hill, is of that age. *Venericardia urutiensis* Marwick (Urenui beds, Tongaporutuan) persists in far northern New Zealand as *V. reinga* Powell, with *V. penerectangularis* Bartrum and Powell as a Pliocene representative (Opoitian, Kaawa). This is apparently a northern (? warm water) lineage, and species closer to *difficilis* appear in the latest Miocene (Kapitean) and Lowest Pliocene (Opoitian) of New Zealand and Chatham Islands (*waikohuensis* Marw., *beata* Marw.). *V. lilliei* Fleming, from the lower Waitotaran of southern Hawke's Bay, is a further approach to the Recent forms, but is much smaller and more rectangular in shape. The Waitotaran is apparently the earliest occurrence of large forms of *V. australis* in New Zealand and the line persists, with minor changes, into the Recent fauna. A tendency to insular sub-speciation is shown by the Nukumaruan *V. titirangiensis* Marwick (Chatham Islands), but no geographic races have been recognized in the recent population, which ranges throughout New Zealand, Stewart and Chatham Islands, but seems to be extinct in the Subantarctic. Among the unnamed Pliocene forms of *purpurata* the Waitotaran population at Wilkies Bluff* is similar to *haskelli* in general appearance and size, but has a more sloping posterior dorsal margin and lacks the characteristic dentition.

In assessing the age significance of *Venericardia haskelli,* of which the closest known relative is from the Waitotaran, the possibility must be considered that this group of large *Venericardia* ancestral to *purpurata* had its origin in a southern life zone and populated New Zealand from the south in the Waitotaran. The present restriction of the *uritiensis-reinga* line to the extreme north of New Zealand and the approximate coincidence in time, of this postulated invasion with an inferred northward movement of other mollusca (Fleming, 1944) are considerations which would permit the dating of the Campbell Island fauna as somewhat earlier than Waitotaran without violence to the affinity between *Venericardia haskelli* and *V. purpurata.*

The specific name is chosen as a tribute to Mr. D. O. Haskell, Aerodromes Engineer, Works Department, who organised the wartime expeditions to the Subantarctic Islands.

* The relegation of Wilkies Bluff to the Nukumaruan Stage by Laws (1940) is not accepted, since Wilkies Bluff is virtually the type locality of Park's Waitotara Coralline beds, on which the Waitotaran stage is based.

MACTRIDAE

Longimactra n.sp. aff. **elongata** (Q. & G.)

The Campbell Island fossils constitute a new species of *Longimactra,* but it is undesirable to burden the nomenclature with a name based on such poorly preserved shells. Shell similar in size and general shape to *elongata,* but with a straighter, less convex, posterior dorsal margin, and with more regular sculpture extending all over the disc and not confined (as it is in *elongata*) to the dorsal and distal margins.

Longimactra is limited to a restricted range of facies and is not a common fossil before the Castlecliffian. *L. leda* (Hutton) from the Oligocene of Trelissick Basin is the oldest known species; in the mid-Tertiary there is a long gap without known representatives. Specimens akin to the Recent *L. elongata* are next present in a number of uppermost Miocene or early Pliocene faunas in Taranaki (Morgan and Gibson, 1927, pp. 42, 43), listed as early Waitotaran in age but possibly as old as Kapitean. The genus is not uncommon in later Pliocene rocks. Judging by the poor material available, the Campbell Island species is closest to, and conspecific with, the form from Taranaki.

Longimactra elongata (Q. & G.) is found throughout the main islands of New Zealand and at Stewart Island and Chatham Islands, but has not been noted in the Subantarctic Recent fauna.

Veneridae

Tawera cf. subsulcata (Suter)

The single specimen is an incomplete shell embedded in matrix so that only the inner surface is exposed. In the shell material radial structure was clearly developed, and a fine pattern of concentric ridges showed beneath them. Careful etching with acid has shown that the fine ridges are not the outer sculpture but are developed on the inner surface of the outer shell layer. The true sculpture consists of wide-spaced coarse concentric ridges, about half as numerous as the structural ridges; there are about 6 ridges in the last 4 mm. of the shell, which is 12 mm. in height. The spacing of ribs is similar in *subsulcata* of the same height, but better material would be necessary for more exact comparison.

T. subsulcata is common in the middle Pliocene (Waitotaran and Nukumaruan Stages) of New Zealand and is related to *T. bollonsi* Powell, Recent, Auckland Islands.

Erodonidae

? Notocorbula humerosa (Hutton)

A very poorly preserved imprint of a valve 17 by 10·5 mm., is similar in shape to left valves of the above species, but is much larger and has finer concentric sculpture. *Notocorbula humerosa* and its close allies last appear in the Kapitean stage, but in view of the uncertainty of the determination of the Campbell Island specimen it is best to ignore it in discussion of the age of the breccias.

GASTROPODA

Cymatiidae

Austrosassia n.sp.

An incomplete exterior cast with shell material adhering to the imprint is a species of *Austrosassia* close to an unnamed form from the Waitotaran of Dannevirke and Wairoa. Shell about 30 mm. in height; varices spaced at about 130°; about 12 radial folds per whorl, nodular at periphery; some 10 regular spiral threads above and an equal number below the periphery. No *Austrosassia* have been seen intermediate in age between *A. zealta* Laws (Altonian stage, Miocene) and the unnamed Waitotaran species; the Campbell Island specimen is closer to the latter.

The living *Austrosassia parkinsoniana* (Perry) is a warm water gastropod not found further south than Auckland Province. The presence of the genus in the breccias is evidence that the seas around Campbell Island were appreciably warmer at the time of their deposition than they are at present.

The Campbell Island fossil Brachiopods have been seen by Profesosr R. S. Allan, who considered that their state of preservation was such that no exact systematic work could be undertaken on them. The notes which follow have been prepared to put the fauna on record.

Tegulorhynchia squamosa (Hutton)

One small undistorted but incomplete specimen from calcareous band 240 ft. above sea-level, west cliff of Mount Dumas, agrees in shape and sculpture with a topotype from Trelissick Basin (? Duntroonian). There do not appear to be any late Tertiary records of this type of shell.

Tegulorhynchia aff. **antipoda** (Thomson) aff. **nigricans** (Sow.)

Two large damaged shells, one juvenal, and one ventral valve, from calcareous band in breccia 240 ft. above sea-level, cliff west of Mount Dumas, and one juvenal shell from loose blocks below west cliff of Mount Dumas. The series shows the variability in shape of *antipoda* and *nigricans;* the ribbing is finer than in *nigricans* except in one juvenal in which it is coarser and is decidedly imbricate near the ventral margin. The adults are more inflated and are more strongly folded than *antipoda. T. antipoda* has a long Miocene range and *T. nigricans* is recorded from the Pliocene and Recent fauna of New Zealand, including Stewart and Chatham Islands, but has not been reported from the Recent Subantarctic fauna.

Terebratulina suessi (Hutton)

A single crushed specimen from the Shoal Point breccia falls within the range of variation of this species which Allan (1930, p. 12) notes may be composite. *T. suessi* ranges from Paleocene (specimen identified by Allan, *loc. cit.,* from Tioriori, Chatham Islands) to early Pliocene (Opoitian) at Momoeatoa, Chatham Islands, but has a more restricted mid-Tertiary range in New Zealand.

Liothyrella cf. **gravida** (Suess)

Large specimens of *Liothyrella* are common at some of the fossiliferous localities, particularly in the calcareous band 240 ft. above sea-level on the west cliff of Mount Dumas. The collection contains shells of a great variety of shapes, including individuals which approach the outward appearance of several species judging by diagnoses and figures presented by Allan (1932). The largest specimen is 74 mm. in length, but is closer in shape to *gravida* than to *magna.* Smaller specimens (49 mm.) have the broad shape of *magna,* but are more inflated and have more swollen beaks than topotypes of that Oligocene species.

Other specimens approach *L. boehmi* in shape, and extreme examples have the elongate form of *L. concentrica* (Hutton). The configuration of the beaks and the size of the foramen are equally variable. Without better material it is difficult to divide the series into several species, and it seems just as reasonable to consider the Campbell Island *Liothyrella* population an extremely variable one related to *gravida* (Suess) as that species is interpreted by Allan.

Neothyris campbellica (Filhol)

Neothyris n.sp.

Specimens of *Neothyris* are not uncommon in the breccia at Shoal Point, which is possibly the type locality of *Waldheimia campbellica* Filhol. Further examples are from the cliff just above sea-level halfway between Mounts Dumas and Eboulé and from loose blocks below the west cliff of Mount Dumas. At Shoal Point two forms occur: one is an elongate ovoid shell with high acute beaks and appears separable from the other, a broader shorter shell, with lower beaks, tending to greater inflation when adult. It is the latter species, tentatively identified with *campbellica,* which occurs elsewhere in the fossiliferous breccias. The distinctness of *campbellica* from *ovalis* (Hutton) cannot be decided on the available material, especially as Hutton's name is at present used to cover a number of Pliocene species in New Zealand. The Campbell Island shell is very similar to large inflated *Neothyris* from the New Zealand Pliocene.

Terebratella n.sp. aff. **sanguinea** (Leach)

A single individual from 300 ft. above sea-level, cliff south-west of Mount Paris, in calcareous breccia. The specimen is small and relatively narrow (15 by 12 mm.). It is narrower than *morioria* Allan, and than most immature *sanguinea,* although occasional Castlecliffian specimens of the latter have a similar outline. The beaks and foramen are smaller than in *sanguinea* and the foramen is smaller than in *morioria.* There are about 24 costae on the dorsal valve, formed by bifurcation of interpolation between about half that number of initial costae. From the Miocene *radiata,* the species differs in shape, form of beak and finer ribbing. *T. sanguinea* is a Recent species inhabiting southern New Zealand and the Auckland Islands; *T. morioria* Allan (Chatham Islands) is earliest Pliocene, and *T. radiata* Hutton is a New Zealand Oligocene and (?) Miocene species.

ECHINOIDEA

Spatangidae

Eupatagus n.sp.

An echinoid from locality 79, calcareous band 20 ft. above sea-level, cliff west of Mount Dumas, has been submitted to Dr. H. B. Fell, Victoria University College. Dr. Fell reports that the echinoid, "on extraction from the matrix, proves to be an almost complete specimen of the Spatangid genus *Eupatagus,* evidently an undescribed species." Description of the species and discussion of its affinities must await a revision of New Zealand Tertiary Echinoderms at present in preparation by Dr. Fell.

Eupatagus ranges from Paleocene, a single species surviving in Australia (Davies, 1935, p. 104). Previous records of *Eupatagus* from New Zealand (Tate, 1894, pp. 123, 124) are from the Oligocene of Cobden and Cape Farewell, so that its occurrence in the Campbell Island breccia suggests a survival of the genus there, as in Australia, to a later date than elsewhere.

Species / Age	Oligocene	Lower Miocene	Upper Miocene	Opoitian	Lower Pliocene: Lower Waitotaran	Lower Pliocene: Upper Waitotaran	Upper Pliocene	Recent
Grandaxinea chambersi (Marsh.)		(*monsadusta*)						
Chlamys aff. *delicatula* (Hutton)					—	—	—	—
Lima robini n.sp.					—		(*waipipiensis*)	
Limatula maoria Fin.				—	—	—	—	—
Modiolus altijugatus Marw.			—					
Venericardia haskelli n.sp.					—		(*australis*)	
Longimactra aff. *elongata* (Q. and G.)			— ? —	—	—	—	—	—
Tawera aff. *subsulcata* (Suter)						—	—	
Austrosassia n.sp.					— —			
Tegulorhynchia cf. *squamosa* (Hutton)	—	— ?						
Tegulorhynchia cf. *antipoda* (Thomson)	—	—	— ?					
Terebratulina suessi (Hutton)	—	—	—	—				
Liothyrella cf. *gravida* (Suess)		—	—	—				
Neothyris campbellica (Filhol)				—	(*ovalis*)		—	—
Terebratella aff. *sanguinea* (Leach)				— ?	—	—	—	—

TABLE II—Time-distribution in the Tertiary of New Zealand and Chatham Islands of the members of the Campbell Island breccia fauna or their closest relatives.

THE AGE OF THE CAMPBELL ISLAND BRECCIAS

The occurrence together of forms of both Miocene and Pliocene affinity points to either a late Miocene or early Pliocene age for the Campbell Island breccias, but more exact correlation with the several possible stages of the New Zealand Tertiary is difficult.

Table II shows the approximate range in time in New Zealand of the species in the Campbell Island fauna or of their closest relatives in New Zealand. Obviously no decision can be made by using the fossils as empirical units of fixed time range: some violence must be done to existing knowledge of the range of some or other of the fossils and it is necessary to consider certain theoretical conceptions before deducing which of the fossils present are more reliable time indicators than others.

(1) The first complicating factor is the possibility that Campbell Island was an island at the time of deposiiton of the breccia. Many island faunas are anomalous.

Insular isolation speeds the development of endemic forms, and at the Chatham Islands such endemic forms of generic rank (e.g., *Pitella, Kahua, Bassinaria*) are recorded from beds correlated with the Opoitian and Nukumaruan Pliocene stages. There is, however, no such extreme endemism in the small Campbell Island faunule. Another character of insular faunas is the persistence of archaic organisms, sheltered from the competition of more advanced relatives. Thus *Pachymelon,* widespread in New Zealand shallow-water Tertiary deposits, now persists as a relict genus at the Chatham Islands (and in deep water off New Zealand). This may be a reasonable explanation of the occurrence of forms of mid-Tertiary affinity (*Grandaxinea chambersi, Terebratulina, Tegulorhynchia* cf. *squamosa, Eupatagus*) in a fauna which otherwise appears of late Tertiary age.

(2) The second point to be considered is that the synchronous faunas of areas separated by seven to ten degrees of latitude might show differences correlated with climate. A fauna at Campbell Island might differ from a contemporary fauna in the North Island by the presence of cold water species and the absence of warm water species. Although *Chlamys delicatula* and *Tawera subsulcata* are classed as cold water organisms in the New Zealand mid-Pliocene (Fleming, 1944), the presence of *Austrosassia* sp. in the Campbell Island faunule makes it unlikely that contemporary seas there were colder than cool temperate: nevertheless, the *Chlamys* and *Tawera* are *southern* species, which seem to have moved north to populate New Zealand (temporarily) in the upper Waitotaran and Nukumaruan stages.

(3) This leads to consideration of a further aspect of correlation. If the succession of faunas in a given locality is due, not entirely to the development of autochthonous lineages in that locality, but, in part at least, to the replacement of elements in the fauna by related forms which had arisen in other regions as allopatric representatives, then the correlation of distant faunas must allow for the direction of movement of migrating faunas.

There is much to suggest that life zones were moving northward in the late Miocene and early Pliocene and it would not be unexpected to find that representatives of the generic and infra-generic groups which first appeared in the Pliocene of the New Zealand mainland had been existing at earlier periods in the Subantarctic Islands. In the Campbell Island breccia fauna, the *Venericardia, Lima, Chlamys* and *Tawera,* and the brachiopods of Pliocene affinity might come under this heading.

(4) It would be unwise to allow the occurrence of brachiopoda of Miocene aspect to unduly influence the correlation. Brachiopods are notoriously sensitive to facies differences and, further, the Southern Hemisphere is strewn with brachiopod species which show by their " spotted " relict distribution the irregular persistence of once wide-ranging genera. *Terebratulina* has not yet been reported in the Pliocene of New Zealand, but persisted into the lower Pliocene of the Chatham Islands and still exists in Australia and elsewhere.

Considering the factors enumerated above, it seems reasonable to correlate the fauna with the Opoitian or early Waitotaran stages of New Zealand rather than with the Upper Miocene, although the uppermost Miocene Kapitean stage remains a possibility. More exact correlation cannot be made with the information available. An early Pliocene age determination is in accord with the affinity of *Lima robini* n.sp. with the lower Waitotaran *L. waipipiensis*. *Grandaxinea chambersi* and some of the brachiopods are regarded as Miocene lingerers persisting into the Pliocene in insular isolation. *Venericardia haskelli* n.sp. is considered the precursor of a line which invaded New Zealand proper in the Waitotaran.

AFFINITIES OF THE CAMPBELL ISLAND BRECCIA FAUNA

The affinities of all the fossil species in the Campbell Island breccias are with New Zealand species and the fauna is merely a peripheral fauna of the New Zealand region. The presence of the distinctive endemic Neozelanic genus *Longimactra* emphasizes this conclusion.

If (as is possible) the dispersal of some shallow water mollusca is restricted to shorelines or shallow seas, their presence at Campbell Island may be taken to support the previous existence of more continuous land between Campbell Island and New Zealand than now exists, but certain anomalies in the fauna discussed above suggest that Campbell Island had been isolated from New Zealand for some time prior to the deposition of the breccias.

Scanty as the breccia fauna is, it contains several genera no longer living in the New Zealand Subantarctic: *Lima* (large species), *Grandaxinea, Venericardia, Longimactra,* and the brachiopods other than *T. sanguinea* (which persists at the Auckland Islands). The Campbell Island Recent molluscan fauna includes no species to suggest a post-Miocene immigration from New Zealand, and can be regarded as a remnant of the once more widspread New Zealand marine fauna impoverished by the rigours of the Pleistocene, and reinforced by wide-ranging Subantarctic elements of great vagility.

TEMPERATURE FACIES OF THE CAMPBELL ISLAND BRECCIA FAUNA

Grandaxinea, Lima (large species), *Venericardia, Longimactra,* and several of the surviving brachiopods do not range further south in New Zealand Recent seas than the northern boundary of the Subantarctic Zone of surface waters. *Austrosassia* has not been recorded further south than northernmost New Zealand, in the Subtropical Zone. The living representatives of *Chlamys delicatula* and *Tawera subsulcata* are southern, apparently cool water types not entering subtropical waters.

The evidence points to more temperate oceanographic conditions at Campbell Island during the deposition of the breccias.

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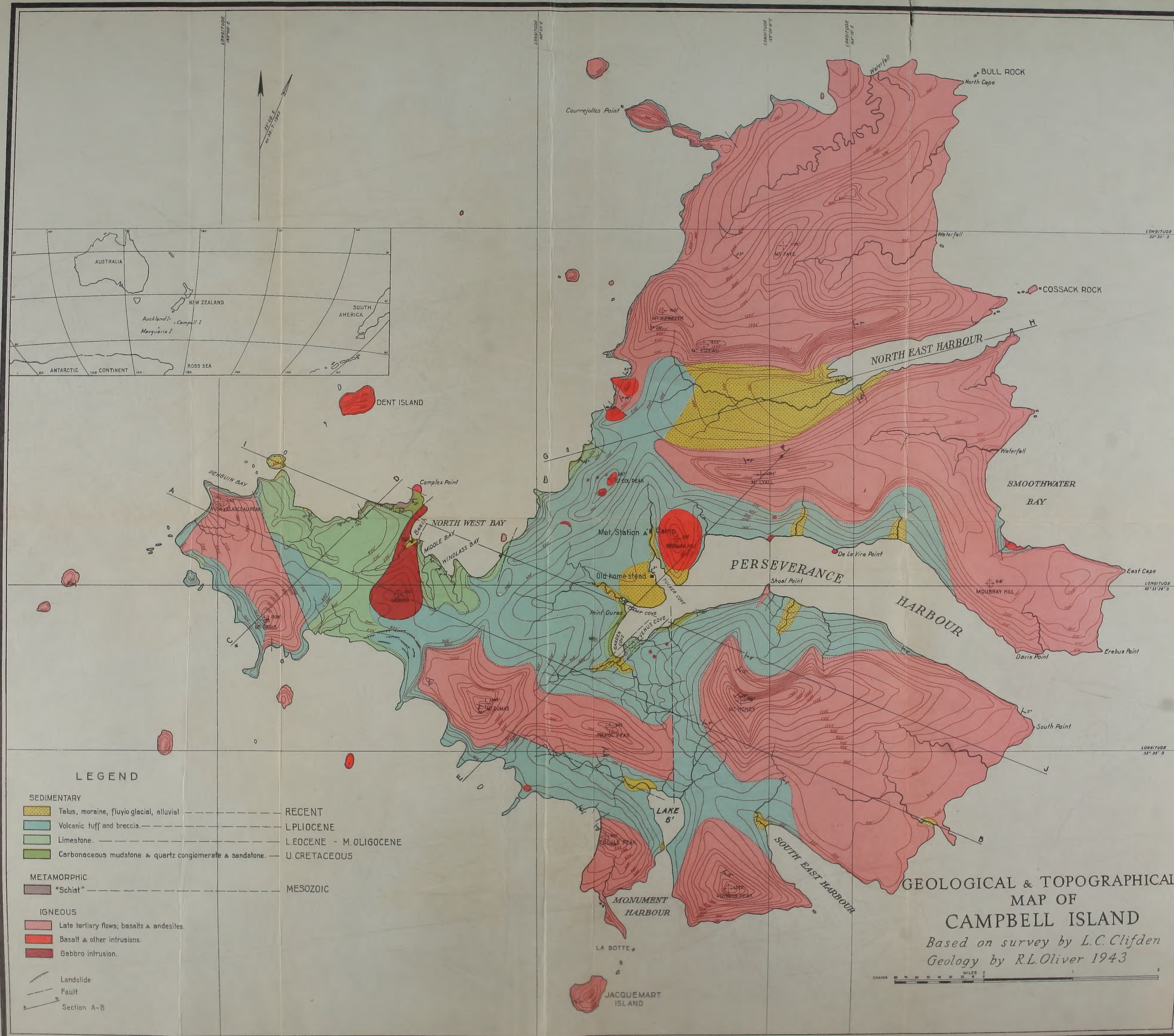
GEOLOGICAL & TOPOGRAPHICAL MAP OF CAMPBELL ISLAND
Based on survey by L.C. Clifden
Geology by R.L. Oliver 1943
LEGEND
SEDIMENTARY
Talus, moraine, fluvio glacial, alluvial — RECENT
Volcanic tuff and breccia — L.PLIOCENE
Limestone — L.EOCENE - M.OLIGOCENE
Carbonaceous mudstone & quartz conglomerate & sandstone — U.CRETACEOUS
METAMORPHIC
"Schist" — MESOZOIC
IGNEOUS
Late tertiary flows; basalts & andesites.
Basalt & other intrusions.
Gabbro intrusion.
Landslide
Fault
Section A-B
AUSTRALIA
NEW ZEALAND
SOUTH AMERICA
Auckland I.
Campbell I.
Macquarie I.
ANTARCTIC CONTINENT
ROSS SEA
BULL ROCK
North Cape
Courrejolles Point
Waterfall
COSSACK ROCK
NORTH EAST HARBOUR
DENT ISLAND
PENGUIN BAY
Complex Point
NORTH WEST BAY
MIDDLE BAY
WINDLASS BAY
Met. Station
Camp
Old homestead
De La Vire Point
PERSEVERANCE HARBOUR
Shoal Point
SMOOTHWATER BAY
East Cape
MOUBRAY HILL
Davis Point
Erebus Point
Point Duras
CAMP COVE
TUCKER COVE
VENUS COVE
GARDEN COVE
South Point
LAKE B'
MONUMENT HARBOUR
SOUTH EAST HARBOUR
LA BOTTE
JACQUEMART ISLAND
MILES
CHAINS

NEW ZEALAND LOCALITIES (lithology from F. & M., 1940)

TABLE SHOWING STRATIGRAPHICAL CORRELATION BETWEEN CAMPBELL ISLAND AND MACQUARIE ISLAND.

Age	*Banks Peninsula*	*North Auckland*	*Dunedin*	*Gisborne and Taranaki*	*Poor Knights Island*	*Opoiti?*	*Whaingaroa?*	*Oamaru*	*West Coast of South Is.*	*N. Auckland Hawke's Bay N. Canterb'y.*	*Amuri Bluff*	*Macquarie Is.*	*Campbell Island*		*Fauna*	*Nature of the Activity.*
M. or U. Pliocene	Basalts (Speight, 1917)	Andesites, basalts, dolerites, rhyolites (Marshall, 1907)	Basalts (Marshall, 1914)										Basaltic and andesitic lava flows	East Coast Formation		Quieter volcanic activity. Extrusion of basaltic and andesitic lavas.
L. Pliocene				U. Tertiary tuffs (Benson, 1921)	Late Tertiary rhyolitic breccias (Bartrum 1936-37)	Opoitian facies?	Whaingaroan facies?					Late Tertiary basaltic and andesitic conglomerates, breccias and lavas	Marine and terrestrial tuffs and volcanic breccia	Shoal Point Formation	Mollusca and brachiopoda	Explosive volcanic activity. Deposition of tuffs and volcanic breccias.
													Unconformity			
M. Oligocene													Argillaceous limestone	Tucker Cove Formation	*Vulvulina pennatula*, etc.	
L. Oligocene								Limestones	Mudstones			Tertiary *Globigerina* ooze	Argillaceous limestone		*Bolivinopsis cubensis*, etc.	Marine transgression. Deposition of limestone and other sediments.
													Argillaceous limestone		*Plectina agrestior*, etc.	
L. Eocene										Calc. argillitic beds			Argillaceous limestone		*Bolivinopsis spectabilis*, etc.	
U. Cretaceous											Arg. lstn. and calc. sands		Quartz conglom. and carb. mdstn.	Garden Cove Formation	*Gaudryina whangaia*	
											Unconformity	Unconformity	Unconformity			Regression. Folding and erosion of Mesozoic rocks.
											Basement	Basement	Basement			